2008-06

Enhancing the operational effectiveness of the Ground-Based Operational Surveillance System (G-BOSS)

Midgette, William D.

Monterey, California. Naval Postgraduate School

http://hdl.handle.net/10945/4134

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

ENHANCING THE OPERATIONAL EFFECTIVENESS OF THE GROUND-BASED OPERATIONAL SURVEILLANCE SYSTEM (G-BOSS)

by

William D. Midgette

June 2008

Thesis Advisor:	Thomas W. Lucas
Co-Advisor:	Doug Burton
Second Reader:	Sergio Posadas

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** June 2008	**3. REPORT TYPE AND DATES COVERED** Master's Thesis

4. TITLE AND SUBTITLE Enhancing the Operational Effectiveness of the Ground-Based Operational Surveillance System (G-BOSS)	**5. FUNDING NUMBERS**
6. AUTHOR(S) William D. Midgette	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited	**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

The majority of casualties in the ongoing conflicts in Iraq and Afghanistan are due to improvised explosive devices (IEDs). To counter this threat, the Marine Corps directed that a persistent surveillance capability be identified and fielded as soon as possible. As a result, the development and fielding of the Ground Based Operational Surveillance System (G-BOSS) occurred rapidly. G-BOSS consists of a tower, multiple cameras, and a combat operations center (COC). Today, scores of these systems are in use. However, minimal guidance has been provided to operators on effective techniques, tactics, and procedures (TTPs). Furthermore, the benefits of adding additional sensors to G-BOSS and networking multiple systems are not clear.

This research investigates these issues through the use of an agent-based simulation. Specifically, thousands of computational experiments, utilizing a state-of-the-art experimental design, were run on a scenario based on concurrent live developmental tests at 29 Palms by the Marine Corps Operational Test and Evaluation Activity (MCOTEA). The experiments assessed the ability of the system to correctly classify objects (e.g., snipers, IED emplacement, and mortar teams, as well as neutrals and friendly forces) over a variety of enemy actions, G-BOSS configurations, and tactical choices. The results indicate that the most critical factor in determining the level of situational awareness provided by G-BOSS is, by far, placement of the towers. Moreover, little benefit is seen in coordinating the towers and COCs unless motion detection radars are used. With use of the motion detection radar, the synchronization of multiple systems dramatically enhances the overall performance of G-BOSS.

14. SUBJECT TERMS Improvised Explosive Device (IED), Simulation, Design of Experiments (DOE), Ground Based Operational Surveillance System (G-BOSS)	**15. NUMBER OF PAGES** 70
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

ENHANCING THE OPERATIONAL EFFECTIVENESS OF THE GROUND-BASED OPERATIONAL SURVEILLANCE SYSTEM (G-BOSS)

William D. Midgette
Captain, United States Marine Corps
B.S., Auburn University, 1999

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
June 2008

Author: William D. Midgette

Approved by: Thomas W. Lucas
Thesis Advisor

Doug Burton
Co-Advisor

Sergio Posadas
Second Reader

James N. Eagle
Chairman, Department of Operations Research

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

The majority of casualties in the ongoing conflicts in Iraq and Afghanistan are due to improvised explosive devices (IEDs). To counter this threat, the Marine Corps directed that a persistent surveillance capability be identified and fielded as soon as possible. As a result, the development and fielding of the Ground Based Operational Surveillance System (G-BOSS) occurred rapidly. G-BOSS consists of a tower, multiple cameras, and a combat operations center (COC). Today, scores of these systems are in use. However, minimal guidance has been provided to operators on effective techniques, tactics, and procedures (TTPs). Furthermore, the benefits of adding additional sensors to G-BOSS and networking multiple systems are not clear.

This research investigates these issues through the use of an agent-based simulation. Specifically, thousands of computational experiments, utilizing a state-of-the-art experimental design, were run on a scenario based on concurrent live developmental tests at 29 Palms by the Marine Corps Operational Test and Evaluation Activity (MCOTEA). The experiments assessed the ability of the system to correctly classify objects (e.g., snipers, IED emplacement, and mortar teams, as well as neutrals and friendly forces) over a variety of enemy actions, G-BOSS configurations, and tactical choices. The results indicate that the most critical factor in determining the level of situational awareness provided by G-BOSS is, by far, placement of the towers. Moreover, little benefit is seen in coordinating the towers and COCs unless motion detection radars are used. With use of the motion detection radar, the synchronization of multiple systems dramatically enhances the overall performance of G-BOSS.

THIS PAGE INTENTIONALLY LEFT BLANK

THESIS DISCLAIMER

The reader is cautioned that the computer programs presented in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logical errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF SYMBOLS, ACRONYMS, AND ABBREVIATIONS

AOR	Area of Responsibility
CDD	Capabilities Development Directorate
CDIB	Capabilities Development Integration Board
CART	Classification and Regression Tree
COC	Combat Operations Center
C2	Command and Control
C-IED	Counter-Improvised Explosive Devices Technology Directorate
DTA	Defense Technology Agency
DCRI	Detection, Classification, Recognition and Identification
FoS	Family of Systems
G-BOSS	Ground Based Operational Surveillance System
GCS	Ground Control Station
GUI	Graphical User Interface
IED	Improvised Explosive Device
IDF	Indirect Fire
ISR	Intelligence, Surveillance and Reconnaissance
JIEDDO	Joint Improvised Explosive Device Defeat Organization
KIA	Killed in Action
MSTAR	Man-Portable Surveillance and Target Acquisition Radar
MANA	Map Aware Non-Uniform Automata
MAGTF	Marine Air Ground Task Force
MCOTEA	Marine Corps Operational Test and Evaluation Activity
MCCDC	Marine Corps Combat Development Command
MCISR-E	Marine Corps Intelligence Surveillance and Reconnaissance-Enterprise
MCSC	Marine Corps Systems Command
MOE	Measure of Effectiveness
NGA	National Geospatial-Intelligence Agency
NPS	Naval Postgraduate School
NOLH	Nearly Orthogonal Latin Hypercube
NZDF	New Zealand Defense Force
OIF	Operation Iraqi Freedom
RAID	Rapid Aerostat Initial Deployment
SEED	Simulation Experiments and Efficient Design
SA	Situational Awareness
TTP	Tactics, Techniques and Procedures
UAS	Unmanned Aircraft Systems
VOIP	Voice Over Internet Protocol
WIA	Wounded in Action

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

First and foremost, I want to thank my beautiful wife Angela. The quality of my thesis is is a direct result of your love, patience, understanding and support. Words will not and can not express the love and gratitude I have for you.

I want to thank Professor Tom Lucas, Commander Doug Burton, LtCol Sergio Posadas and Mary McDonald. These four incredible people kept me on track and never let me lose focus. Had it not been for their support, this thesis would not have been possible. I appreciate your efforts and I will never forget it. Last, but not least, I want to thank Colonel Ed Lesnowicz, USMC (retired) for his “motivational” pep talks, and SEMPER FIDELIS.

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

The majority of casualties in the ongoing conflicts in Iraq and Afghanistan are due to improvised explosive devices (IEDs). To counter this threat, coalition forces have directed that a persistent surveillance capability be identified and fielded as soon as possible. As a result, the Ground Based Operational Surveillance System (G-BOSS) was developed and fielded. G-BOSS consists of a tower, multiple cameras, and combat operations centers (COCs). Today, hundreds of these systems are in use. However, minimal guidance has been provided to operators on effective techniques, tactics, and procedures (TTPs). Furthermore, the services are unsure of the benefits of adding additional sensors to G-BOSS and networking multiple systems.

This research provides Coalition forces with analytical support for initial and further development of TTPs, modernization efforts, and operational employment for G-BOSS. The analysis is guided by three questions from the Marine Corps Operational Test and Evaluation Activity (MCOTEA), who is tasked with testing G-BOSS in order to enhance the operational effectiveness of the system. The questions are:

- What critical factors determine the level of situational awareness (SA) provided by G-BOSS?
- Does coordination via the COC improve the effectiveness of G-BOSS?
- Does use of motion detection radar improve the effectiveness of G-BOSS?

This thesis uses agent-based simulation, state-of-the-art design of experiments, and graphical and statistical analysis methods to investigate these questions.

The goal of the simulation is to measure the level of SA provided by G-BOSS. The measures of effectiveness (MOEs) associated with this goal are the proportion of correct classifications of friendly, hostile and neutral role players per test trial. An additional MOE is whether or not the IED emplacers were detected. Factors of interest include, but are not limited to: the slew rate of G-BOSS, the distance between the pairs of Rapid Aerostat Initial Deployment (RAID) towers, the configuration of the COCs (coordinated or stand-alone), and the presence of Man-Portable Surveillance and Target Acquisition Radar (MSTAR) with the G-BOSS sensors.

The simulated scenario in this study models a live developmental test conducted by the Marine Corps Operational Test and Evaluation Activity (MCOTEA) on the capabilities and limitations of G-BOSS conducted in April 2008 in 29 Palms, California. The scenario used in this thesis is test trial #15, an IED scenario conducted at night. Trial #15 includes an IED-emplacement team, composed of three hostile role players simulating IED emplacement at a predetermined time and location. The remaining neutral, friendly and hostile forces participating in the trial (also consisting of three members each) maneuver through the test area while G-BOSS operators use the system to determine hostile acts or intent. Figure ES-1 shows the terrain and agent depictions used in the simulation model.

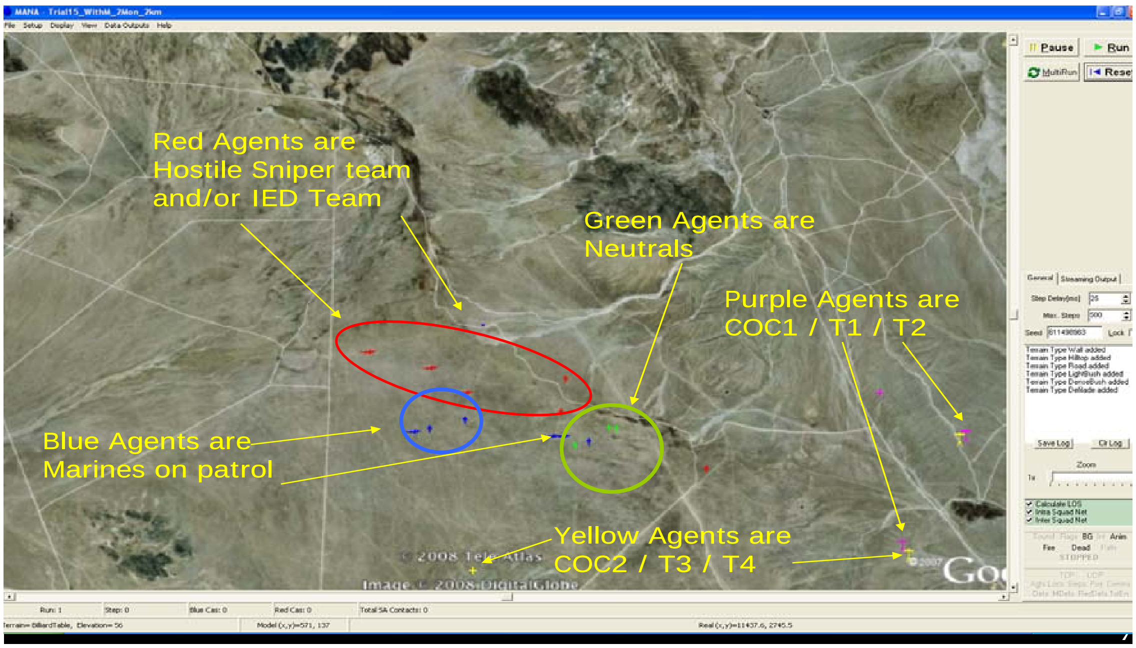


Figure ES-1. MANA model screen shot.

Map Aware Non-Uniform Automata (MANA) is the modeling environment used in this thesis. MANA represents the key temporal and spatial elements of this tactical scenario and facilitates quickly constructing “medium-resolution” simulations that can be broadly explored using sophisticated design of experiments and computing clusters. Nearly Orthogonal Latin Hypercubes (NOLHs) and data farming enabled an analysis of a large set of possibilities. The conclusions in the research are based on over twenty

thousand simulated tests with varying threats (i.e., snipers and IED emplacement teams) neutrals and friendly forces over a variety of enemy actions, G-BOSS configurations, and tactical choices.

The insights gained in this analysis are:

- The positioning of the towers is the most critical factor associated with enhancing the operational effectiveness of G-BOSS. A distance of 4 km between G-BOSS towers results in a proportion of correct identifications of 0.91 while a distance of 2 km results in a proportion of 0.53. When G-BOSS is employed in open terrain, more dispersion results in better performance.
- The stealth of the role-players has a significant effect on the proportion of correct identifications. This result is intuitive and helps validate the model, since snipers and IED emplacers tend to use stealth to mask their hostile acts or intent. Increased training of G-BOSS operators' level of vigilance is a countermeasure to mitigate enemy stealth.
- Without the presence of MSTAR, the coordinated G-BOSS configuration produces a slightly larger proportion of correct identifications than the stand-alone G-BOSS configuration. The coordinated G-BOSS configuration results in an overall proportion of correct identification of 0.51, while the stand-alone G-BOSS configuration results in an overall proportion of correct identification of 0.49. The results of the comparison between the G-BOSS configurations are not practically significant. This is based on the marginal increase of approximately two percentage points between the coordinated G-BOSS configuration and the stand-alone G-BOSS configuration. Further, this finding answers the question of underutilization: Stand-alone employment of G-BOSS is nearly as effective as a coordinated employment of G-BOSS without MSTAR.
- With MSTAR, the coordinated G-BOSS configuration produces a significantly larger proportion of correct identifications than what the stand-alone configuration produces. The coordinated G-BOSS configuration results in an overall proportion of correct identifications of 0.71 and the stand-alone configuration results in an overall proportion of correct identifications of 0.47. This result is practically and statistically significant. MSTAR facilitates the detection of more agents. MSTAR coupled with data fusion at the COC affords commanders an enhanced capability.
- The emplacement of the IED was detected in 76% of all of the simulation excursions conducted (which varied 13 factors associated with G-BOSS or the role-players). This is promising since G-BOSS's mission is to counter the threat of IEDs.

I. INTRODUCTION

A. MOTIVATION

The improvised explosive device (IED) has proven effective against Marines in Operation Iraqi Freedom (OIF). As a result, the largest number of Marines killed in action (KIA) and/or wounded in action (WIA) during OIF is attributed to the IED. In addition to IEDs, insurgents have expanded their range of tactics, techniques, and procedures (TTPs) against Marine forces in Iraq with sniper attacks and hit and run indirect fire (IDF) teams. The potential to cause high-density, melodramatic attacks to test the resolve of our nation in fighting the Global War on Terror is the central value of the IED to insurgents.

In an attempt to mitigate further casualties by these popular tactics, the Marine Corps Combat Development Command (MCCDC), Capabilities Development Directorate (CDD), and Capabilities Development Integration Board (CDIB), under the guidance of the Marine Corps' Intelligence, Surveillance, and Reconnaissance (ISR) strategy, directed that a persistent surveillance capability be identified and fielded immediately. The ISR strategy is a component of the Marine Corps ISR-Enterprise (MCISR-E), whose focus is to integrate air, ground, and space sensors into a network capable of detecting, locating, identifying, and targeting threats.

The Ground-Based Operational Surveillance System (G-BOSS)—the focus of this thesis—is one system within a larger Family of Systems (FoS) predicated on the concept of the Marine Corps' ISR strategy.

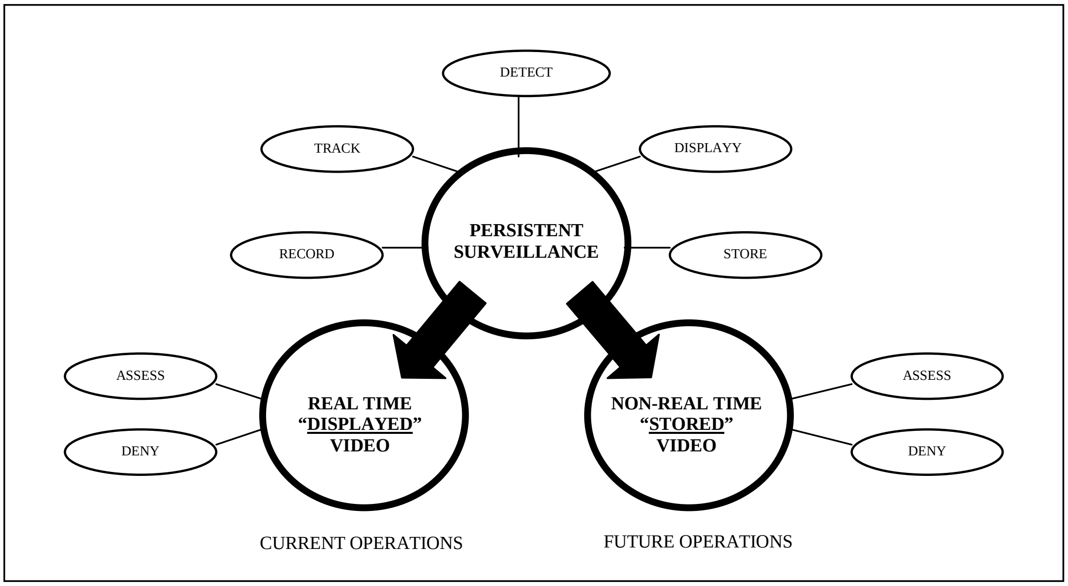


Figure 1. G-BOSS operational construct.

G-BOSS is a force protection, camera-oriented, day/night, expeditionary tool that provides the ability to detect, track, display, record, assess, deny, and store video to counter the threat of IEDs and disrupt insurgency activities (Marine Corps Combat Development Command, 2007) as shown in Figure 1, the G-BOSS operational construct. G-BOSS referred to throughout this analysis is composed of a Rapid Aerostat Initial Deployment (RAID) 107-foot mobile tower, two cameras: a Star SAFIRE IIIFP and a T-3000, a Man-Portable Surveillance and Target Acquisition Radar (MSTAR) sensor, and a Ground Control Station (GCS).

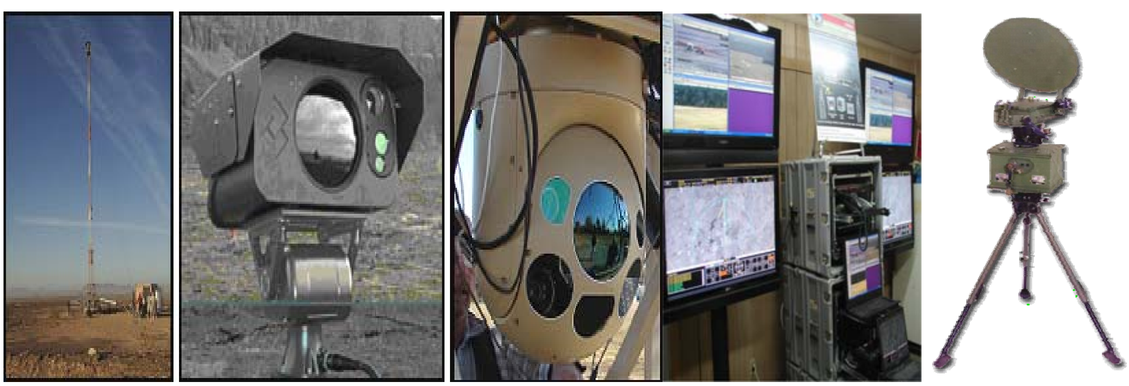


Figure 2. G-BOSS components from l-r: RAID tower, T-3000, Star SAFIRE IIIFP, RGS, MSTAR. (from MCOTEA's G-BOSS Detailed Assessment Plan, April 2008 [Best viewed in color])

B. THE PROBLEM

The objective for G-BOSS is to detect, identify, and track insurgent activities; specifically those associated with the emplacement of IEDs. Since its initial employment in late spring 2007, G-BOSS has contributed to the reduction of the loss of life among Marine forces due to IEDs. One potential end-state is a fully networked G-BOSS capable of integration with unmanned aircraft systems (UAS), command and control (C2) assets, and fire support systems that will increase situational awareness (SA) and aid commanders in conducting current and future offensive operations to disrupt insurgent activity.

G-BOSS is currently deployed in a stand-alone configuration with minimal centralized coordination and consolidation of sensor data. Employment of G-BOSS in a stand-alone configuration is not due to fault, nor negligence. The immediate need for G-BOSS, coupled with an aggressive implementation of the system in theater, did not afford time to develop TTPs for G-BOSS. The Marine Corps has a four-phase employment plan for G-BOSS. The Marine Corps is in phase two of its four-phase employment of G-BOSS. The phases are:

- *Phase 1*
  - Manual operation
  - View video at base of each tower
  - Radio communication to a combat operations center (COC)
- *Phase 2*
  - Manual operation
  - Video feed to COC
  - COC directs camera slewing
- *Phase 3*
  - Cameras controlled from COC
  - Automatic camera slewing
- *Phase 4*
  - Integrated network throughout province (multiple COCs)

The Marine Corps Systems Command (MCSC), Counter-Improvised Explosive Devices Technology Directorate (C-IED) wants to know if the G-BOSS employment approach in Phase 2 provides more SA than the G-BOSS employment approach in Phase 1. This thesis addresses the question: How can Marines deployed *now* best employ G-BOSS? The Marine Corps Operational Test and Evaluation Activity (MCOTEA) conducted a developmental test of G-BOSS to evaluate the capabilities and limitations of the system, in order to enhance its operational effectiveness for deployed commanders. Results from this test are intended to improve the phased deployment of G-BOSS.

C. PURPOSE

The purpose of this thesis is to develop a simulation using an agent-based model (ABM) that represents the live developmental test conducted by MCOTEA. The goal is to provide coalition forces with analytical support to improve G-BOSS TTPs and enhance the operational effectiveness of the system. The simulated operational experience provided by this analysis helps facilitate future tests of G-BOSS capabilities and can potentially serve as an operational planning tool for commanders.

Further, this study serves as a proof of concept of the capability that the Simulation Experiments and Efficient Design (SEED) Center for Data Farming at the Naval Postgraduate School (NPS) can provide to support the Joint Improvised Explosive Device Defeat Organization (JIEDDO) in the war against IEDs. The SEED Center for Data Farming mission statement is to “advance the collaborative development and use of simulation experiments and efficient designs to provide decision makers with timely insights on complex systems and operations.” JIEDDO has the mission to “lead, advocate, and coordinate all Department of Defense actions in support of Combatant Commanders’ and their respective Joint Task Forces’ efforts to defeat improvised explosive devices as weapons of strategic influence.” The SEED Center (http://harvest.nps.edu) and JIEDDO (https://www.jieddo.dod.mil/) websites provide more detail.

D. RESEARCH QUESTIONS

This thesis simulates MCOTEA's live test and conducts a comparative, quantitative analysis of G-BOSS employment TTPs to enhance the operational effectiveness of G-BOSS. While this analysis is by no means exhaustive, the following questions are addressed:

- What critical factors determine the level of SA provided by G-BOSS?
- Does coordination via the COC improve the effectiveness of G-BOSS?
- Does use of motion detection radar improve the effectiveness of G-BOSS?

E. METHODOLOGY

This thesis uses agent-based simulation, state-of-the-art design of experiments, and advanced data analysis methods to analyze the critical factors associated with the level of SA provided by G-BOSS. The process is to simulate a scenario based on a live developmental test conducted by MCOTEA with G-BOSS. The simulated model is then replicated and analyzed. The analysis process uses a technique called data farming, which involves using high-performance computing to run the simulation thousands of times, while simultaneously varying many input parameters. As a result, data farming provides insights into complex problems through the exploration of a multitude of possible outcomes.

This thesis uses an agent-based distillation, which is a type of computer simulation that attempts to capture the critical factors of interest in combat without explicitly modeling all of the physical details. The tool used is Map Aware Non-Uniform Automata (MANA), developed by the New Zealand Defense Technology Agency (DTA). More information about MANA can be found at https://teams.nzdf.mil.nz/sites/mana/default.aspx.

F. THESIS ORGANIZATION

Chapter II begins with an unclassified description of the equipment and the scenario involved with MCOTEA's test. The chapter concludes with an overview of

MANA and a detailed description of the simulation model created for this thesis. Chapter III offers a discussion on the design of experiments used for this analysis and includes a description of the factors used in this analysis, and an explanation of Nearly Orthogonal Latin Hypercubes (NOLHs). Chapter IV provides a description of the analytical methods used to interpret the results of the simulated tests and concludes with an explanation of the analytical results. Chapter V completes the thesis with a discussion of the insights gained from the analysis and recommends topics for follow-on research.

II. MODEL DEVELOPMENT

Persistent surveillance is the primary capability afforded to the commander by G-BOSS. Under the guidance of the Marine Corps' ISR strategy, G-BOSS will be employed at all levels of the Marine Air Ground Task Force (MAGTF) to perform surveillance of assigned areas of responsibility (AOR). G-BOSS is now employed in a stand-alone configuration. MCSC wants to know if current employment techniques underutilize G-BOSS. MCOTEA's test of G-BOSS addresses that question.

A. G-BOSS TEST OVERVIEW

MCOTEA's developmental test of G-BOSS evaluates its capabilities and limitations. Their assessment included three distinct test events: SA; Detection, Classification, Recognition, and Identification (DCRI); and Track Error. The scenario and simulation model developed for use in this thesis depicts one night time test trial of the SA test event. The SA test event explores whether a coordinated network approach of G-BOSS significantly improves SA over the current uncoordinated, stand-alone tower approach.

MCOTEA measures SA and compares the level of SA between a coordinated and stand-alone tower approach in two steps. First, test trials that use role players in teams of friendly, hostile and neutral personnel to maneuver at varying ranges within G-BOSS's field-of-regard. The G-BOSS operators use the system and determine hostile acts or intent. The second part is to calculate an SA score based on an SA Value Model developed by MCOTEA. Table 1 lists the data requirements necessary to calculate the SA score. To learn more about the MCOTEA Situational Awareness Value Model, contact MCOTEA at www.quantico.usmc.mil/activities/?Section=MCOTEA for a copy of the report detailing the results of the developmental test for G-BOSS.

MCOTEA Test Data Requirements	
Trial Number	Percent of Hostiles Identified
Trial Time	Percent of Neutral Identified
Data Collector	Percent of Friendly Identified
Configuration	Percent of Identification | Detection
MSTAR	Percent of Detections
Enemy Action	Percent of False Detections
Lux	Target Location Error
Temperature	Screen Clutter
Humidity	Current Target Location Error
Wind Speed	Percent of Hostiles Identified Pre-Act
Pressure	False Alarm Rate for Hostiles
Probability of Identification | Cue	Time to Respond to Cue

Table 1. Data requirements for MCOTEA's SA value model.

1. Test Location

The test was conducted at Acorn Range, Marine Corps Air Ground Combat Center, 29 Palms, California, from 15-28 April 2008. In Figure 3, the red colored area depicts the zone in which teams of role players maneuvered against G-BOSS during the SA test event.

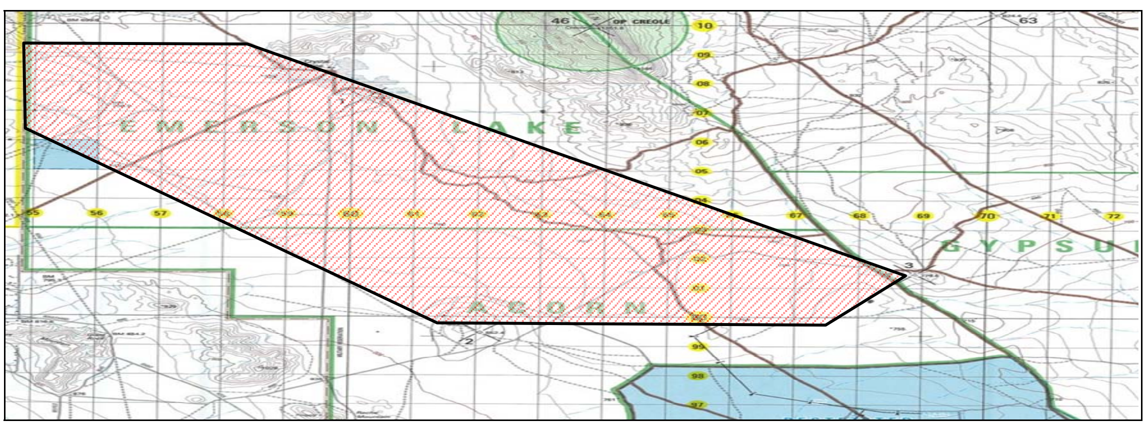


Figure 3. G-BOSS test site. (from MCOTEA's G-BOSS Detailed Assessment Plan, April 2008 [Best viewed in color])

2. Test Equipment

Due to the classified nature of the exact specifications and capabilities of G-BOSS, only a general description is provided. Figure 2, in Chapter I, illustrates G-BOSS undergoing test and evaluation. The Star SAFIRE IIIFP and T-3000 cameras are mounted at the top of the RAID tower. A tactical radio for the transmission of camera and radar data is mounted near the cameras. MSTAR is mounted on the tower, approximately 28 feet above the tower's base. MCOTEA assessed (4) RAID towers, (8) cameras, (4) MSTARs, (4) GCSs, (2) RGSs, and (2) COCs.

3. Test Architecture

Figure 4 shows the test equipment configuration: four RAID 107-foot towers, each configured with one Star SAFIRE IIIFP camera and one T-3000 camera. The G-BOSS sensors were deployed in two distinct configurations: a coordinated network configuration and an uncoordinated, stand-alone configuration. Each tower pair (1 and 2, 3 and 4) spans a 2-km distance. For administrative and logistical convenience, tower pairs were located near each other. COC 1 and COC 2 are located approximately 50 km away from their respective towers.

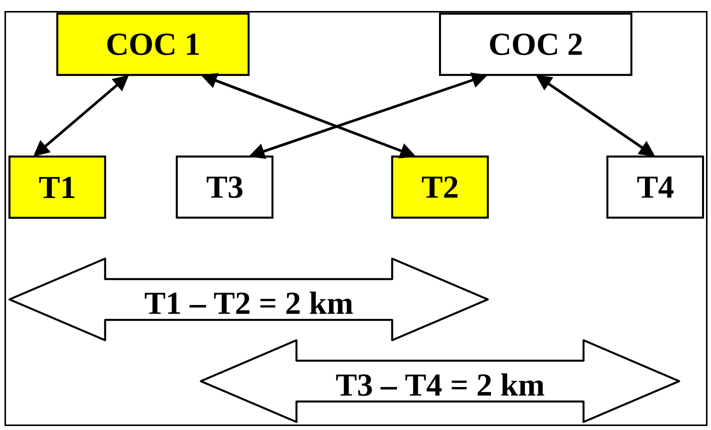


Figure 4. MCOTEA test architecture.

Towers 1 and 2, along with COC 1, were operated in a coordinated network configuration. The coordinated network approach allows COC 1 to optimize the search patterns of the four G-BOSS sensors on Towers 1 and 2. Under this configuration,

COC 1 is able to assist Towers 1 and 2 assess hostile acts or intent during the test trial. COC 1 is able to assist Towers 1 and 2, since it can observe what all four G-BOSS sensors on Towers 1 and 2 can observe.

Towers 3 and 4, along with COC 2, were operated in an uncoordinated, stand-alone configuration. This configuration allows degraded assistance from COC 2 to Towers 3 and 4 during the test trial to assess hostile acts or intent. COC 2 could not observe what Towers 3 and 4 could see, but received updates via voice over internet protocol (VOIP) phone transmission.

4. Situational Awareness (SA) Trial

An SA trial consisted of a predetermined time period wherein a mix of friendly, neutral and hostile role players operated on foot in the field of view of the G-BOSS towers. During this period, some of the hostile role players performed their mission. A trial period starts at either the beginning of a test day or at the end of the previous data collection stop. A trial period ends at a predetermined time for a data collection stop. The two distinct tower and COC configurations operate simultaneously during the trial, so, at a minimum, each data collection stop yields two trials.

The SA trial associated with this thesis was test trial #15, which was an IED scenario conducted on 24 April 2008 at night. The scenario included an IED-emplacement team, composed of three hostile role players simulating IED emplacement at a predetermined time and location. The remaining neutral, friendly and hostile forces participating in the trial (also consisting of three members each) moved through the test area as directed by the test-trial script. The trial concluded upon completion of the hostile act and after MCOTEA called for a data collection stop. G-BOSS operators were provided a table, such as Table 2, to facilitate distinguishing between role players.

Role Player Category	Code	Distinguishing Features
Neutral (N)	N	Middle Eastern Clothing
	N-Shovel	Middle Eastern Clothing w/Shovel
	N-Rifle	Middle Eastern Clothing w/Rifle
Friendly (F)	F-Mortar	Helmet/Flak w/Mortar Tube
	F-Rifle/Scope	Helmet/Flak w/Rifle/Scope
	F-Rifle	Helmet/Flak w/Rifle
	F	Helmet/Flak
Hostile (H)	H-Shovel/IED	Middle Eastern Clothing w/Shovel/IED
	H-Rifle/Scope	Middle Eastern Clothing w/Rifle/Scope
	H-Mortar	Middle Eastern Clothing w/Mortar Tube

Table 2. SA test trial role-player categories.

B. THE MAP AWARE NON-UNIFORM AUTOMATA (MANA) COMBAT SIMULATION TOOL

MANA is the modeling environment used in this thesis. MANA is a time-step, ABM environment developed by the New Zealand DTA in early 2000 for the New Zealand Defense Force (NZDF) after experiencing frustration with combat models based solely on physics. MANA intends to capture "enough physics as is necessary" (McIntosh, Galligan, Anderson, & Lauren, 2007), to capture aspects of human behavior and to represent a wide range of interactions among agents and their environment. In a MANA model, the agents are:

- Map Aware—Agents have SA of the other agents and terrain that is updated by sensors and communications.
- Non-uniform—Individual agents may have different behavior parameters, capabilities, sensors, weapons, and communications.
- Automata—Agents react independently on the battlefield according to their own individual characteristics and awareness.

MANA is a straightforward application that is intuitive and easy to use with a well-developed Graphical User Interface (GUI). More details of this model are readily available in the *MANA User's Manual* and at https://teams.nzdf.mil.nz/sites/mana/default.aspx.

1. Why MANA?

Many aspects of warfare can be explained by physics, such as the trajectory of a projectile to a point of impact or the effective casualty radius of an artillery round. Less tangible elements, such as SA, must also be explained or measured. The nonlinear relationships associated with SA, coupled with the numerous variables involved, make sole dependence on physics-based models ineffective.

MANA represents the key temporal and spatial elements of the tactical scenario. With a clear idea of this scenario and the measure in question, MANA can provide the capability to "explore the greatest range of possible outcomes with the least set-up time" (McIntosh, Galligan, Anderson, & Lauren, 2007).

MANA is used because SA is the primary measure to be analyzed. In the most basic of terms, "SA is knowing what is going on around you" (Endsley & Garland, 2000). Many factors influence the various levels of SA. MANA provides a dynamic and stochastic environment in which many of these factors can be varied and their interactions explored. MANA also facilitates rapid scenario generation based on MCOTEA's developmental test.

C. CHARACTERISTICS OF THE SIMULATION MODEL

The role players and equipment associated with the SA test trial are referred to as agents. An agent is a "character" within the MANA modeling environment with assigned attributes and personality characteristics similar to their actual capabilities.

Detection is defined as one agent being aware of another agent's presence. Classification is a step further. Classification means an agent is able to distinguish if a detected agent is a neutral, hostile or friendly agent. In the MCOTEA test, detection takes on the same definition as in the MANA scenario. Identification in the MCOTEA test is the equivalent to classification in the MANA scenario.

1. Goal

The goal of the simulation is to measure the level of SA provided by G-BOSS for test trial #15. The measures of effectiveness (MOEs) associated with this goal are the

proportion of correct classifications of friendly, hostile and neutral role players per test trial. An additional MOE is whether or not the IED emplacers were detected. Factors of interest include, but are not limited to: the slew rate of G-BOSS, the distance between the pairs of RAID towers, the configuration of the COCs (coordinated or stand-alone), and the presence of MSTAR with the G-BOSS sensors.

2. Scale and Terrain

The implementation of the scenario in MANA requires mapping from real time and real space to simulated time and simulated space. In this simulation model, a time step is equal to 5 seconds of real time. For a 1-hour scenario this equates to 720 model time steps. The default battlefield size for a scenario in MANA is a 200 x 200 grid. The scale of the scenario used in the simulation model is 20 meters per grid square. Thus, a 650 pixel by 500 pixel map grid represents the 13 kilometer by 10 kilometer test area used in the MCOTEA test. Due to the few agents needed for the simulation, a 1-hour simulated test trial completes in approximately 30 seconds of real time per execution on a standard laptop processor. The time and distance scales were chosen to achieve “good enough” resolution to simulate and record the result of agent activities.

The terrain in the model consists of two components: an elevation map and a terrain map as shown in Figure 5. In the elevation map, black represents the lowest level of elevation and white represents the highest elevation. Elevation in MANA is used to block line-of-sight, as appropriate. To obtain the elevation map, the Falcon View software package was used to open the appropriate DTED-2 file that was obtained from the National Geospatial-Intelligence Agency (NGA). The image file acquired with Falcon View was then translated into a bitmap that could be read in by MANA. Finally, within MANA, the user manually enters the difference between high and low points in the image (which corresponds to the black to white spectrum MANA uses to display the elevation file).

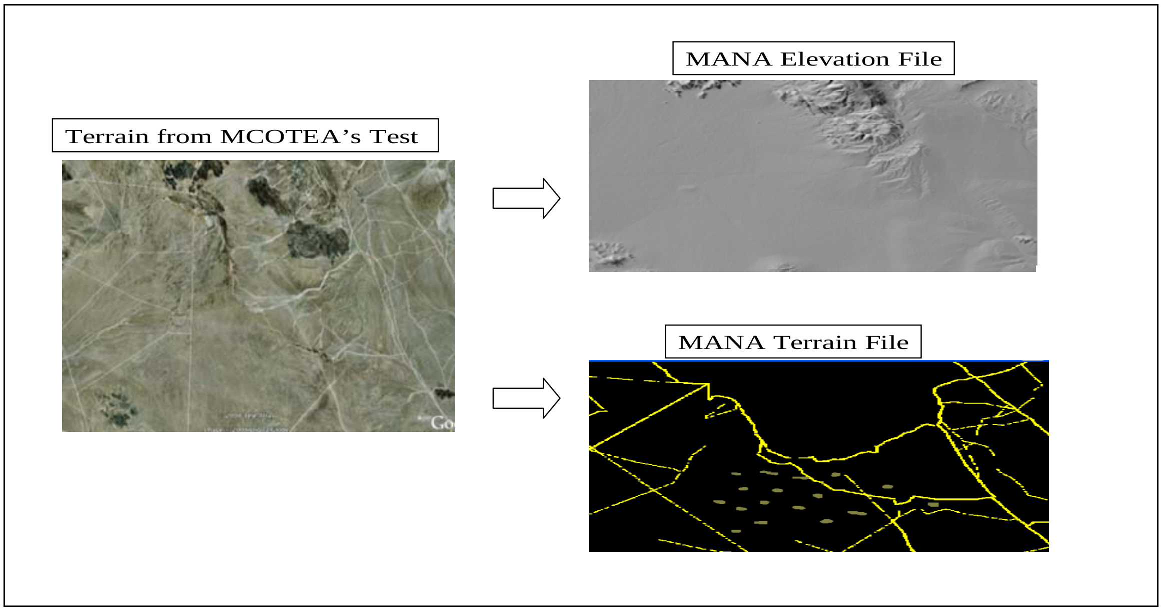
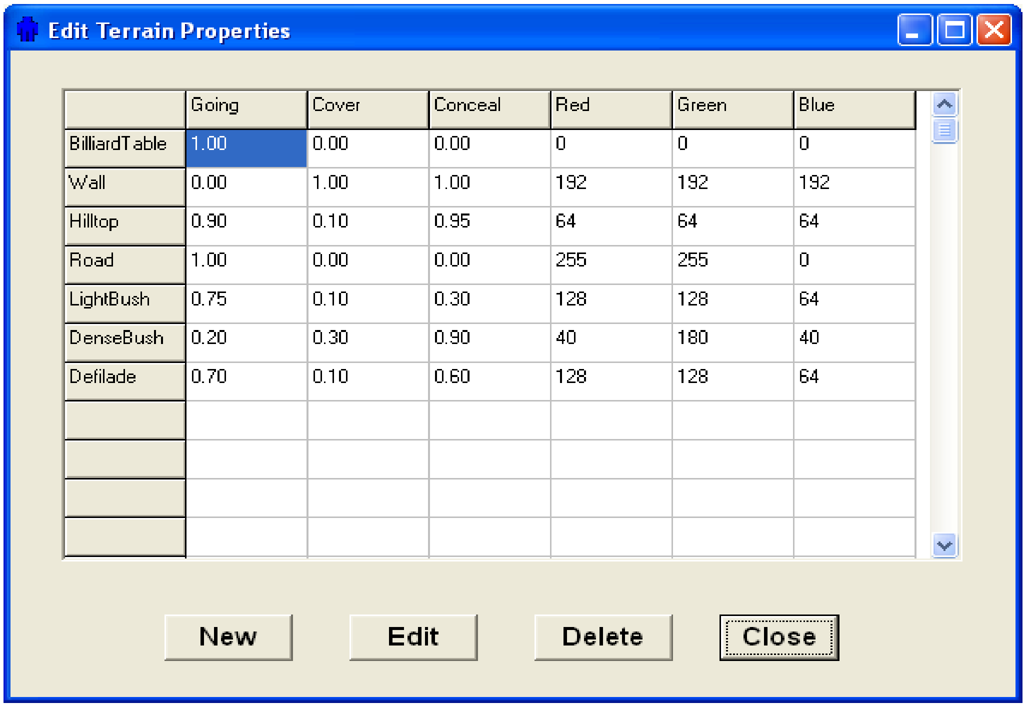


Figure 5. The elevation and terrain files used by MANA were derived from the terrain in the MCOTEA scenario. [Best viewed in color]

The terrain file depicts battlefield terrain in the model. Distinct colors are used to represent terrain features within the model. Figure 6 shows how colored pixels on the terrain map (as defined by their Red-Green-Blue settings) affect the movement speed of the role-players. Figure 6 also shows the level of cover and concealment provided by the terrain. For example, a terrain type created for this scenario called defilade, which is depicted by the brown spots in the MANA terrain file, allows only 70% of the maximum speed for a role-player, 10% protection from fire, and 60% concealment from view. These percentages are used as multipliers in MANA's calculations, and their use is further described in the *MANA User's Manual*.



	Going	Cover	Conceal	Red	Green	Blue
BilliardTable	1.00	0.00	0.00	0	0	0
Wall	0.00	1.00	1.00	192	192	192
Hilltop	0.90	0.10	0.95	64	64	64
Road	1.00	0.00	0.00	255	255	0
LightBush	0.75	0.10	0.30	128	128	64
DenseBush	0.20	0.30	0.90	40	180	40
Defilade	0.70	0.10	0.60	128	128	64

Figure 6. The characteristics of the colors in the terrain file for the MANA model used in this research. (from MANA 4.01.1)

3. Agent Descriptions

a. The Refueler Agent Class

A large portion of the test trial depends upon the agent's stealth as it maneuvers in the test area. To facilitate stealth, an agent named "Refueler" was created to serve the purpose of "refueling" the role-player agents in the scenario, according to its range and probability settings. Receiving fuel from the refueler triggers the agent to temporarily go into a stealth state where it stops moving for 12 time steps (1 minute). The refueler agent is invisible to other agents and provides fuel every 36 time steps (3 minutes) on average.

4. Red Agents (Hostile Role Players)

SA test trial #15 uses two types of hostile role-players: an IED emplacer and a sniper. These agents are referred to as H-ShovelIED and H-RifleScope, respectively.

a. H-ShovelIED

This agent is depicted by a standing red soldier icon on the screenshot shown in Figure 7. This agent moves slowly and stealthily, while seeking defilade positions, until it arrives at the IED emplacement location. During its hostile act, its appearance changes into a larger red soldier icon. The simulated hostile act takes place at approximately time step 360 (30 minutes into the scenario, in accordance with the live test event). The act continues for approximately 120 time steps (10 minutes). During the simulated hostile act, the agent loses the stealth property because it is digging. When it is refueled by the Refueler, this agent stops moving and employs stealth for 12 time steps (1 minute).

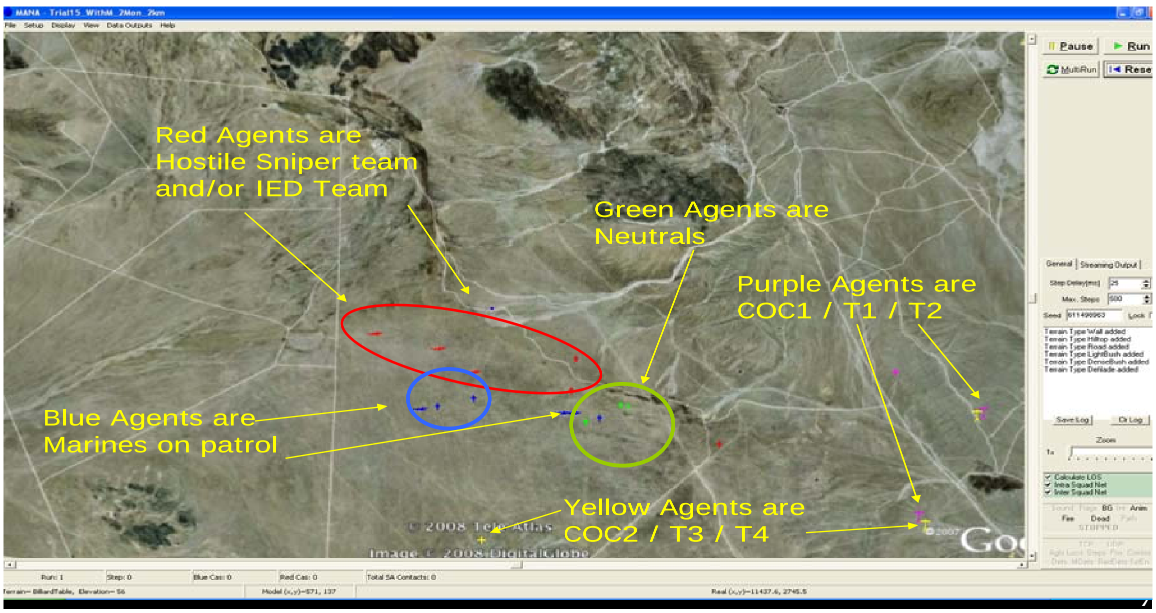


Figure 7. MANA Model Screen Shot. [Best viewed in color]

b. H-RifleScope

This agent is depicted by a red soldier icon in the prone position on the screenshot shown in Figure 7. This agent moves slowly and stealthily seeking cover and concealment from defilade to its final hide position. When it is refueled by the Refueler, this agent stops moving and employs stealth for 12 time steps (1 minute).

5. Blue Agents (Friendly Role Players)

SA test trial #15 uses two types of friendly role-players: a Marine with a rifle and a scope and a Marine with just a rifle. These agents are referred to as F-RifleScope and F(Friendlies), respectively.

a. F-RifleScope

This agent is depicted by a standing blue soldier icon on the screenshot shown in Figure 7. This agent moves slowly and stealthily seeking cover and concealment from defilade to its final hide position. When refueled by the Refueler, this agent stops moving and employs stealth for 12 time steps (1 minute).

b. F(Friendlies)

This agent is depicted by a standing blue soldier icon on the screenshot shown in Figure 7. This agent moves slowly and stealthily seeking cover and concealment from defilade to its final hide position. When refueled by the Refueler, this agent stops moving and employs stealth for 12 time steps (1 minute).

6. Neutral Agents (Neutral Role Players)

SA test trial #15 uses one type of friendly role-player: a local member of the area. This agent is known as N(Neutrals).

a. N(Neutrals)

This agent is depicted by a standing green soldier icon on the screenshot shown in Figure 7. This agent maneuvers in the test area without seeking cover and concealment. This agent does not turn yellow since there is no need for it to be stealthy. This agent simply wanders about the test area.

7. Towers 1 and 2

SA test trial #15 uses two towers with the traits listed below. These agents are referred to as Tower 1 and Tower 2.

a. Tower 1 and Tower 2

These agents are depicted by purple tower icons on the screenshot shown in Figure 7. These agents do not move. They detect and classify other agents in the test area with their three sensors, T-3000, StarSAFIRE IIIFP, and MSTAR. The agents continually scan the test area to classify other agents, and once the tower classifies another agent in the test area, the tower "shoots" a round from its perfectly lethal, perfectly accurate weapon. In the model, shooting/killing is a surrogate for classifying. This is done to simplify the MOE data collection. This approach is reasonable since combat adjudication is not employed. At least three discrete time observations (15 seconds of observation or shots) are required to classify an agent.

Towers 1 and 2 along with COC 1 represent the coordinated network configuration described in the test architecture. To model that configuration, all classification information is passed instantaneously and accurately to COC 1. This approach simulates four monitors, one for each view of each tower's cameras, in COC 1.

8. Towers 3 and 4

SA test trial #15 uses two towers with the same traits. These agents are known as Tower 3 and Tower 4.

a. Tower 3 and Tower 4

These agents are depicted by purple tower icons on the screenshot shown in Figure 7. These agents do not move. They detect and classify other agents in the test area with their three sensors, T-3000, StarSAFIRE IIIFP, and MSTAR. The agents continually scan the test area to classify other agents, and once the tower classifies another agent in the test area, the tower "shoots" a round from its perfectly lethal, perfectly accurate weapon. In the model, shooting/killing is a surrogate for classifying. This is done to simplify the MOE data collection. This approach is reasonable since combat adjudication is not employed. At least three discrete time observations (or shots) are required to classify an agent.

Towers 3 and 4 along with COC 2 represent the stand-alone network configuration described in the test architecture. To model that configuration, the Towers

attempt to pass all classification information to COC 2; however, with delays and inaccuracies. Only one message at a time is passed. This technique simulates the G-BOSS limitation of only monitoring one threat at a time.

9. COC 1 and COC 2

SA test trial #15 uses two COCs with different traits. These agents are called COC 1 and COC 2.

a. COC 1

This agent is depicted by a purple crosshair icon on the screenshot shown in Figure 7. This agent does not move and has no organic sensor associated with it. COC 1 receives classification information from Towers 1 and 2, in a manner that simulates two monitors associated with each tower's cameras. COC 1 performs data fusion on the information received from Towers 1 and 2 to assist the towers with classification of agents. For more detail on MANA data fusion, the *MANA User's Manual* may be consulted. The data fusion capability is used as a surrogate to model the effect of the COC operators assisting with the classification task. COC classification is accomplished in the same manner as classification by a tower.

b. COC 2

This agent is depicted by a yellow crosshair icon on the screenshot shown in Figure 7. COC 2 operates in a similar manner to COC 1. COC 2 receives less information from Towers 3 and 4. Only completed classifications are passed from Towers 3 and 4 to COC 2. COC 2 does not employ data fusion.

THIS PAGE INTENTIONALLY LEFT BLANK

III. EXPERIMENTAL DESIGN

A goal of this thesis is to provide insights that enhance the operational effectiveness of G-BOSS. Experimental design is used to identify the critical factors associated with the level of SA provided by G-BOSS. The experimental design includes selection of factors and measures of effectiveness (MOEs). State-of-the-art techniques are applied to efficiently explore the parameter space through data farming. NOLHs facilitate this approach.

A. MEASURE OF EFFECTIVENESS

A MOE is "a measure of operational success that must be closely related to the objective of the mission or operation being evaluated. A meaningful MOE must be quantifiable and a measure to what degree the real objective is achieved" (The Defense Acquisition University [DAU], 2003). SA is the intangible measure in the center of this analysis. A simple definition of SA is "knowing what is going on around you" (Endsley & Garland, 2000). SA also includes observing the battlespace, processing input from those observations and developing an understanding of the environment, friendly actions and threat activity. Two MOEs are used to quantify SA in this analysis: the percent of correct classifications made by G-BOSS operators and whether or not an IED emplacement is observed.

B. EXPERIMENT FACTORS

The simulation factors chosen for this thesis are based on the developmental test conducted by MCOTEA on G-BOSS. The experiment factors are grouped into three categories: G-BOSS configuration, G-BOSS performance, and battlespace environment. G-BOSS configuration and G-BOSS performance factors can be controlled in the real world by the decision maker. For example, the distance between each G-BOSS RAID tower is dictated by the COC. Battlespace environment factors cannot be controlled in the real world by the decision maker. Examples include the number of hostile, friendly, or neutral personnel in a G-BOSS field-of-regard. Table 3 summarizes the simulation parameters and their ranges used in the experiment.

Factor	Value Range	Explanation
MSTAR / No MSTAR	0 or 1	With or without motion detection radar
Number of COC Monitors	0, 1, 2	Number of monitors per COC
Distance Between Pairs of Towers	2km, 4km	Distance between RAID towers
Cam 1 P(Class)	.01….99	Probability of classification associated with the T-3000 sensor
Cam 1 Class Range	+/- 20%	Probability of classification range associated with the T-3000 sensor
Cam 2 P(Class)	.01….99	Probability of classification associated with the Star SAFIRE IIIFP sensor
Cam 2 Class Range	+/- 20%	Probability of classification range associated with the Star SAFIRE IIIFP sensor
Tower Slew Rate	1 - 3 deg/ts	Surrogate for time it takes to cover the area in high-resolution mode
Latency of Comm to COC	1 min… 15 min	Delay associated with passing contact info from tower to COC
Reliability of Comm to COC	.01….99	Probability that intended message from tower is received by COC
Number of Role-players per Team	2 … 6	Number of role-players per team
Role-player Stealth	.01….99	Level of stealth associated with each role-player
Role-player Speed	.5 km/hr to 2 km/hr	Maneuver speed for each role-player

Table 3. Variable factors in the experimental design. G-BOSS configuration factors are in yellow, G-BOSS performance factors are in white, and Battle space environment factors are in gray. [Best viewed in color]

1. G-BOSS Configuration Factors

The following factors are used to analyze the level of SA provided by G-BOSS:

a. MSTAR or No MSTAR

This is a categorical variable defined by whether the motion detection radar is present or not.

b. Number of COC Monitors

This is the number of monitors in the COC.

c. Distance Between Pairs of Towers

This is the distance between RAID towers.

2. G-BOSS Performance Factors

The following factors are used to analyze the level of SA provided by G-BOSS on a basis of performance:

a. Camera 1 P(Classification)

This is the probability of classification associated with the T-3000 sensor.

b. Camera 1 Classification Range

This is the probability of classification range associated with the T-3000 sensor.

c. Camera 2 P(Classification)

This is the probability of classification associated with the Star SAFIRE IIIFP sensor.

d. Camera 2 Classification Range

This is the probability of classification range associated with the Star SAFIRE IIIFP sensor.

e. Tower Slew Rate

This is a surrogate for time it takes to cover the area in high-resolution mode.

f. Latency of Communication to COC

This is the delay associated with passing contact information from the tower to the COC.

g. Reliability of Communication to COC

This is the probability that messages from the tower are received by the COC.

3. Battle Space Factors

The following factors were chosen to analyze the level of SA provided by G-BOSS, based on elements of the battlefield that are uncontrollable:

a. Number of Role-players per Team

This is the number of role-players per team.

b. Role-player Stealth

This is the level of stealth associated with each role-player.

c. Role-player Speed

This is maneuver speed for each role-player.

C. NEARLY ORTHOGONAL LATIN HYPERCUBES (NOLH)

NOLHs are a space-filling experimental design technique developed by COL Thomas Cioppa, United States Army, at the Naval Postgraduate School (NPS) in 2002. This technique allows for the exploration of a large number of input parameters in an efficient number of runs, while maintaining nearly orthogonal design columns (Cioppa & Lucas, 2007). A design of 13 factors at just two levels, each using a full-factorial approach, would require nearly a quarter of a million runs (8,192 design points x 30 reps = 245,760 total runs). Using a crossed design with a stacked NOLH for the quantitative factors, the number of runs is reduced significantly to 23,760 (792 design points x 30 reps = 23,760) runs and the quantitative factors are more extensively varied. Figure 8 shows the NOLH design spreadsheet used for this analysis and Figure 9 shows the space-filling property of the NOLH technique.

	A	B	C	D	E	F	G	H	I	J	K	L
2	low level	112.5	0.01	142.5	0.01	12	0.01	3	0.01	2	1	0
3	high level	187.5	0.99	237.5	0.99	180	0.99	14	0.99	6	3	0
4	decimals	0	2	0	2	0	2	0	2	0	0	0
5	factor name	ClassRng	n1PClass	ClassRng	n2PClass	mLatency	Reliability	titySpeed	ityStealth	umPerTm	SlewRate	
6		188	0.1	184	0.19	159	0.62	11	0.47	6	2	0
7		180	0.99	154	0.38	91	0.19	11	0.32	6	2	0
8		178	0.44	229	0.16	17	0.59	11	0.04	3	3	0
9		155	0.87	238	0.41	170	0.16	12	0.07	4	1	0
10		183	0.04	187	0.22	128	0.71	7	0.56	2	1	0
11		185	0.93	172	0.29	86	0.22	5	0.87	2	2	0
12		164	0.47	235	0.26	12	0.65	7	0.9	6	1	0
13		152	0.68	232	0.35	164	0.26	5	0.99	4	3	0
14		162	0.26	163	0.53	133	0.32	3	0.19	4	2	0
15		169	0.65	169	0.68	49	0.53	4	0.38	5	1	0
16		166	0.22	214	0.96	70	0.07	4	0.16	4	2	0
17		171	0.71	205	0.93	138	0.96	8	0.41	3	1	0
18		157	0.16	160	0.56	112	0.13	14	0.78	3	2	0
19		176	0.59	178	0.87	38	0.56	13	0.71	3	3	0
20		159	0.19	223	0.9	75	0.01	10	0.75	5	2	0
21		173	0.62	199	0.99	149	0.9	9	0.65	5	3	0
22		150	0.5	190	0.5	96	0.5	9	0.5	4	2	0
23		113	0.9	196	0.81	33	0.38	6	0.53	2	2	0
24		120	0.01	226	0.62	101	0.81	6	0.68	2	2	0
25		122	0.56	151	0.84	175	0.41	6	0.96	5	1	0
26		145	0.13	143	0.59	23	0.84	5	0.93	4	3	0

Figure 8. NOLH Design Spreadsheet.

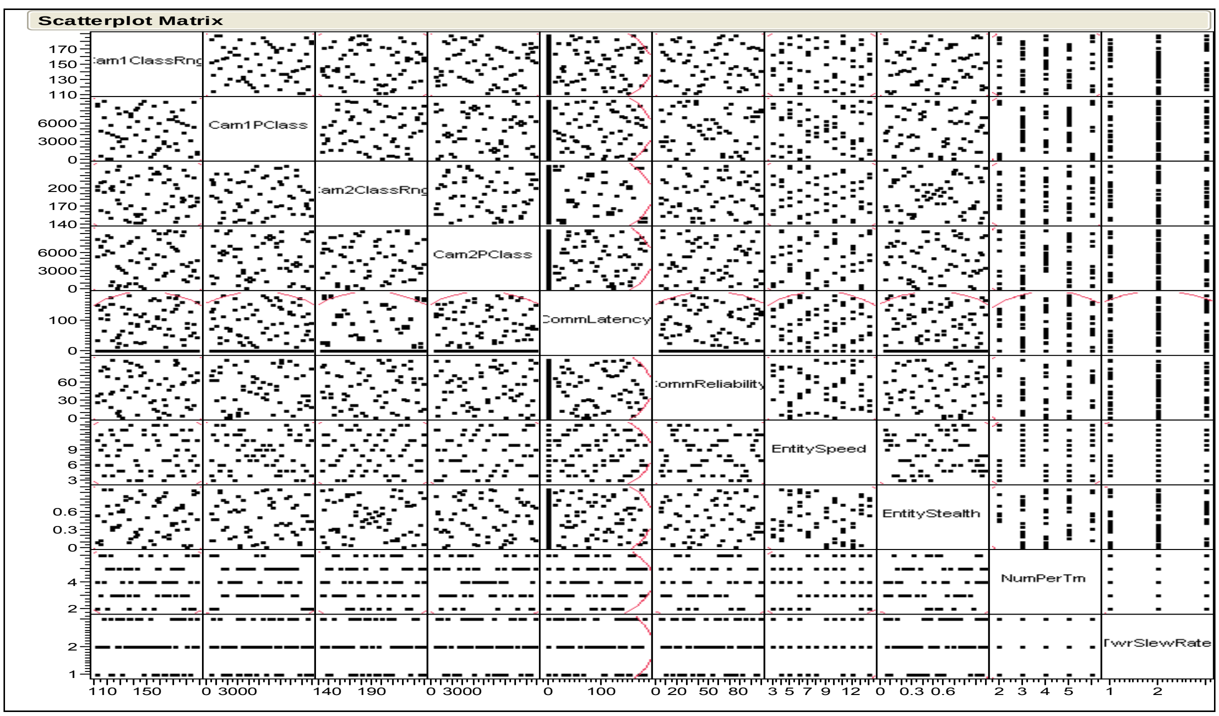


Figure 9. Scatterplot matrix of experiment factors.

Another advantage of NOLH is the negligible correlation among experiment factors, which prevents factor effects being confounded with one another. Figure 10 shows minimal multicollinearity (negligible correlation amongst the experiment factors).

Correlations

	Cam1ClassRng	Cam1PClass	Cam2ClassRng	Cam2PClass	CommLatency	CommReliability	EntitySpeed	EntityStealth	NumPerTm	TwrSlew Rate
Cam1ClassRng	1.0000	-0.0020	-0.0032	0.0025	-0.0049	-0.0032	0.0020	-0.0031	-0.0044	-0.0181
Cam1PClass	-0.0020	1.0000	-0.0018	-0.0115	-0.0026	0.0039	-0.0031	0.0026	0.0219	-0.0131
Cam2ClassRng	-0.0032	-0.0018	1.0000	0.0015	-0.0061	-0.0137	-0.0113	0.0046	0.0033	-0.0482
Cam2PClass	0.0025	-0.0115	0.0015	1.0000	0.0017	-0.0000	-0.0261	0.0074	0.0111	-0.0810
CommLatency	-0.0049	-0.0026	-0.0061	0.0017	1.0000	0.0039	-0.0050	-0.0039	0.0217	-0.0141
CommReliability	-0.0032	0.0039	-0.0137	-0.0000	0.0039	1.0000	0.0005	0.0115	-0.0149	-0.0304
EntitySpeed	0.0020	-0.0031	-0.0113	-0.0261	-0.0050	0.0005	1.0000	-0.0219	0.0252	0.1074
EntityStealth	-0.0031	0.0026	0.0046	0.0074	-0.0039	0.0115	-0.0219	1.0000	-0.0063	0.1257
NumPerTm	-0.0044	0.0219	0.0033	0.0111	0.0217	-0.0149	0.0252	-0.0063	1.0000	-0.0358
TwrSlew Rate	-0.0181	-0.0131	-0.0482	-0.0810	-0.0141	-0.0304	0.1074	0.1257	-0.0358	1.0000

650 rows not used due to missing or excluded values or frequency or weight variables missing, negative or less than one.

Figure 10. Experiment factor pairwise correlation matrix.

IV. DATA ANALYSIS

After defining the problem, scenario, MOEs and experimental design, the simulation is executed to generate output data. The next task is the analysis of the data generated by data farming the simulation model. The analysis provided in this chapter is the result of an iterative and exhaustive process of applying various statistical techniques to the simulation output. Not every step of that exhaustive process is detailed in this section. Models and techniques resulting in significant findings about G-BOSS operational effectiveness are included in this chapter. JMP Statistical Discovery Software Version 7 is the primary tool used for this analysis. Details of this data analysis software are readily available at www.jmp.com.

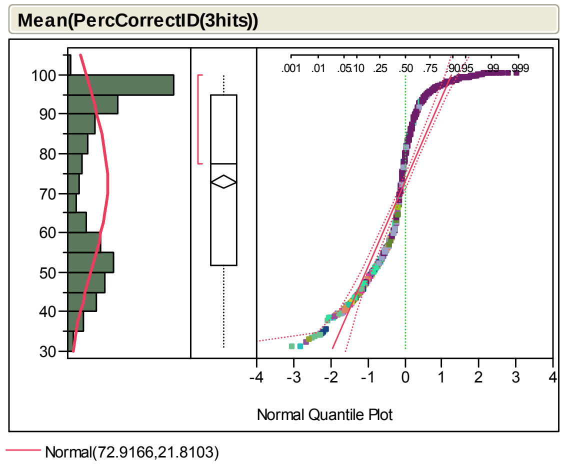
The analysis evaluates three specific research questions about enhancing the operational effectiveness of G-BOSS:

- What critical factors determine the level of SA provided by G-BOSS?
- Does coordination via the COC improve the effectiveness of G-BOSS?
- Does use of motion detection radar improve the effectiveness of G-BOSS?

Each question is addressed in this chapter, along with an explanation of the analysis technique and results.

A. DATA SUMMARY

A summary of the MOE data is provided in Figures 10 and 11. For clarity of presentation, the means of the 780 design points are graphed. The data summary includes the distribution data and 95% confidence intervals for the MOEs. Based on the distribution of the *Mean-IED-Detected* MOE, the IED emplacement was detected 76% of the time. The *Mean-Percent-Correct-Identifications* MOE distribution data shows G-BOSS provides an average of 72% correct identifications in SA trial #15. Neither MOE data fits a Normal distribution. A Normal distribution of the data is not expected or required.



Moments

Mean	72.91662
Std Dev	21.810319
Std Err Mean	0.7809347
upper 95% Mean	74.449606
lower 95% Mean	71.383634
N	780

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	72.91662	71.383634	74.449606
Dispersion	σ	21.810319	20.779092	22.950053

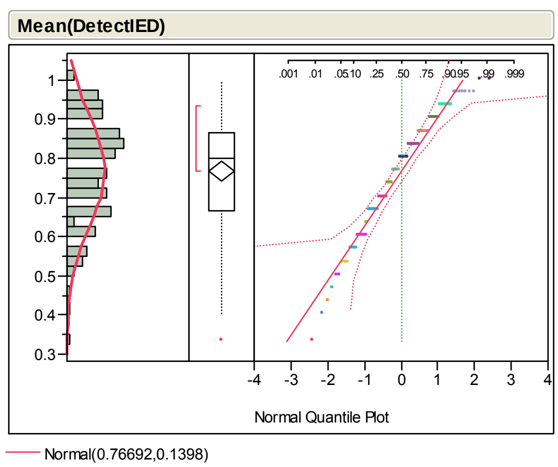
Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.876874	0.0000*

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Figure 11. Data summary for the *Mean-Percent-Correct-Identifications* MOE.



Moments

Mean	0.7669231
Std Dev	0.1397978
Std Err Mean	0.0122611
upper 95% Mean	0.7911819
lower 95% Mean	0.7426642
N	130

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	0.7669231	0.7426642	0.7911819
Dispersion	σ	0.1397978	0.1246219	0.1592157

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.962815	0.0013*

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Figure 12. Data summary for the *Mean-IED-Detected* MOE.

B. SA CRITICAL FACTORS

Stepwise Regression and Classification and Regression Trees (CART) are the primary data analysis techniques used to identify the critical factors and interactions that determine the level of SA provided by G-BOSS in this scenario.

1. Stepwise Regression

Regression is a common statistical technique used for investigating the effects of factors on a response variable (Montgomery, Peck, & Vining, 2006) or MOE. This technique is computationally intensive and allows the possibility to overfit a model. Stepwise regression reduces the parameter space to only those factors with a specified significance level by incrementally adding and deleting factors to the regression model. The result of a stepwise regression identifies the significant or critical factors that affect the response or MOE. Further, stepwise regression provides parameter estimates for the significant factors that result in the most preferred *R*-squared value. By definition, the *R*-squared value is the explained proportion of the variation in the response from fitting the model to the input values (Montgomery et al., 2006).

The initial stepwise regression model for this study investigated all main effects and two-way interaction terms of the 13 experimental factors on the *Mean-Percent-Correct-Identifications* MOE as the response variable. A 0.05 level of significance is used in the development of this model. The results identified the most critical factors. Thus, the preferred regression model used in this study includes these seven critical factors and some of their interactions:

- *Distance Between Pairs of Towers*
- *Number of Role-players per Team*
- *Role-player Speed*
- *Tower Slew Rate*
- *Number of COC Monitors*
- *MSTAR/no MSTAR*
- *Role-player Stealth*

Figure 13 is a visual representation of the preferred model. The plot of the actual versus predicted response displays how closely the preferred model explains the MOE. This conclusion is made based on how well the data points follow the diagonal line. The residual by predicted plot shows that the assumption of heteroscedasticity, or an absence of a pattern in the residuals, is violated. Prediction is not the purpose of this model. The

purpose is gaining insight into the relative factor effects and their interactions. Thus, this finding of mild nonheteroscedasticity does not diminish any insights gained from this model.

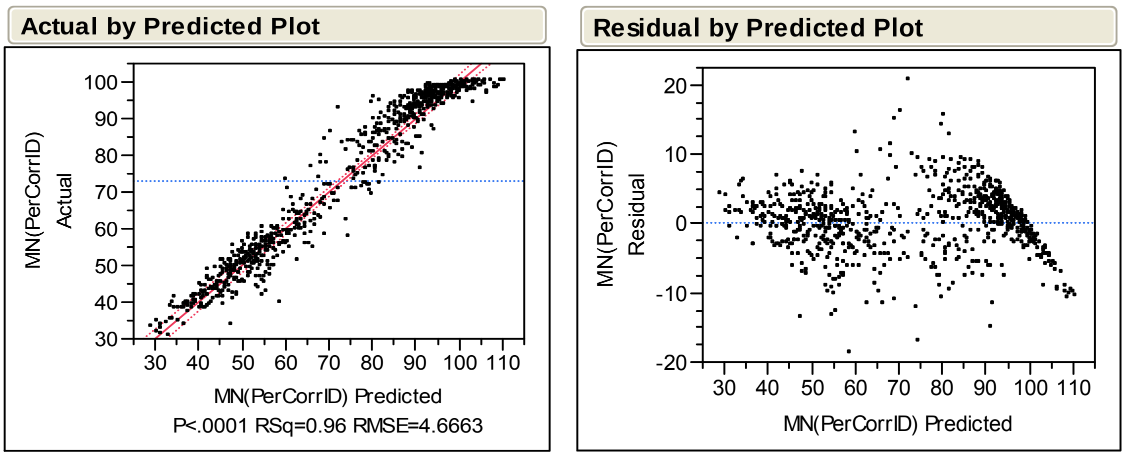


Figure 13. Predicted versus actual *Mean-Percent-Correct-Identifications* and associated residual plot verifying the absence of pattern in the residuals.

The preferred model in this study yields an R-squared of 0.96: 96% of the variability in the mean percent of correct identifications is explained by the critical factors identified in the model. The analysis of variance section in Figure 13 shows that the model is highly significant. This conclusion is based on the extremely low p-value for the F statistic.

Response MN(PerCorrID)

Summary of Fit

RSquare	0.956869
RSquare Adj	0.954225
Root Mean Square Error	4.666343
Mean of Response	72.91662
Observations (or Sum Wgts)	780

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	45	354579.86	7879.55	361.8664
Error	734	15982.67	21.77	Prob > F
C. Total	779	370562.53		0.0000*

Figure 14. The R-squared value and significance of the stepwise regression model.

The effect of each critical factor on the MOE is shown in Figure 15. The absolute magnitude of the *t*-Ratio indicates the relative influence a factor has on the outcome of the MOE. The *114.01* value for *Distance Between Pairs of Towers [4]* is the largest value in the table and, thus, has the most statistical significance in explaining the MOE. The *Distance Between Pairs of Towers* factor is categorical and takes on the value of 2 km or 4 km. This factor has a positively correlated relationship with the MOE. When *Distance Between Pairs of Towers* is set at 4 km, the MOE value produced in the simulation increases. This is contrasted with the second highest magnitude value of *–22.88* for the *Number of Role-players per Team*. This factor is a nonzero integer and is negatively correlated with the MOE (i.e., as *Number of Role-players per Team* increases, the MOE value decreases). Inspection of the remaining *t*-Ratio values yield an understanding of how the factors influence the MOE. The proportion of variance explained by each factor is shown in Figure 16. Again, the positioning of the towers is by far the most important factor.

Scaled Estimates

Nominal factors expanded to all levels
Continuous factors centered by mean, scaled by range/2

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	73.164831	0.173026	422.86	0.0000*
COCsWithMon{0&1-2}	-2.527669	0.264089	-9.57	<.0001*
COCsWithMon{0-1}	-1.668293	0.204633	-8.15	<.0001*
DistBetw Tw rs[2]	-19.04862	0.167082	-114.01	0.0000*
DistBetw Tw rs[4]	19.048616	0.167082	114.01	0.0000*
MSTAR[No]	-2.272248	0.167082	-13.60	<.0001*
MSTAR[Yes]	2.2722483	0.167082	13.60	<.0001*
Cam1ClassRng	1.3094355	0.280208	4.67	<.0001*
Cam1PClass	1.8591256	0.278335	6.68	<.0001*
Cam2ClassRng	0.6913811	0.276819	2.50	0.0127*
Cam2PClass	2.1100025	0.279189	7.56	<.0001*
CommLatency	-1.083035	0.366653	-2.95	0.0032*
CommReliability	-0.044681	0.278941	-0.16	0.8728
EntitySpeed	5.2992629	0.275464	19.24	<.0001*
EntityStealth	-3.037041	0.281187	-10.80	<.0001*
NumPerTm	-6.076454	0.265612	-22.88	<.0001*
Tw rSlew Rate	3.8061006	0.23718	16.05	<.0001*
(COCsWithMon{0&1-2}-0.33333)*DistBetw Tw rs[2]	-2.346151	0.263831	-8.89	<.0001*
(COCsWithMon{0&1-2}-0.33333)*DistBetw Tw rs[4]	2.3461505	0.263831	8.89	<.0001*
COCsWithMon{0-1}*DistBetw Tw rs[2]	-0.965988	0.204633	-4.72	<.0001*
COCsWithMon{0-1}*DistBetw Tw rs[4]	0.9659878	0.204633	4.72	<.0001*
(COCsWithMon{0&1-2}-0.33333)*MSTAR[No]	2.5304753	0.177217	14.28	<.0001*
(COCsWithMon{0&1-2}-0.33333)*MSTAR[Yes]	-2.530475	0.177217	-14.28	<.0001*
COCsWithMon{0-1}*MSTAR[No]	1.5296904	0.204633	7.48	<.0001*
COCsWithMon{0-1}*MSTAR[Yes]	-1.52969	0.204633	-7.48	<.0001*
COCsWithMon{0-1}*(EntitySpeed-8.50769)	0.492062	0.334519	1.47	0.1417
(COCsWithMon{0&1-2}-0.33333)*(NumPerTm-4.06154)	1.7237415	0.280892	6.14	<.0001*
COCsWithMon{0-1}*(NumPerTm-4.06154)	1.6956608	0.324039	5.23	<.0001*
DistBetw Tw rs[2]*MSTAR[No]	-2.151542	0.167082	-12.88	<.0001*
DistBetw Tw rs[2]*MSTAR[Yes]	2.1515423	0.167082	12.88	<.0001*
DistBetw Tw rs[4]*MSTAR[No]	2.1515423	0.167082	12.88	<.0001*
DistBetw Tw rs[4]*MSTAR[Yes]	-2.151542	0.167082	-12.88	<.0001*
DistBetw Tw rs[2]*(Cam1ClassRng-150.031)	-0.618336	0.279558	-2.21	0.0273*
DistBetw Tw rs[4]*(Cam1ClassRng-150.031)	0.6183355	0.279558	2.21	0.0273*
DistBetw Tw rs[2]*(Cam1PClass-5003.08)	-1.496109	0.278089	-5.38	<.0001*
DistBetw Tw rs[4]*(Cam1PClass-5003.08)	1.4961085	0.278089	5.38	<.0001*
DistBetw Tw rs[2]*(Cam2PClass-5003.08)	-1.514234	0.279004	-5.43	<.0001*
DistBetw Tw rs[4]*(Cam2PClass-5003.08)	1.514234	0.279004	5.43	<.0001*
DistBetw Tw rs[2]*(CommLatency-64.0821)	1.2360203	0.366	3.38	0.0008*
DistBetw Tw rs[4]*(CommLatency-64.0821)	-1.23602	0.366	-3.38	0.0008*
DistBetw Tw rs[2]*(EntitySpeed-8.50769)	1.1528621	0.274984	4.19	<.0001*
DistBetw Tw rs[4]*(EntitySpeed-8.50769)	-1.152862	0.274984	-4.19	<.0001*
DistBetw Tw rs[2]*(EntityStealth-0.50031)	1.5891095	0.280421	5.67	<.0001*
DistBetw Tw rs[4]*(EntityStealth-0.50031)	-1.58911	0.280421	-5.67	<.0001*
DistBetw Tw rs[2]*(NumPerTm-4.06154)	-2.174915	0.265079	-8.20	<.0001*
DistBetw Tw rs[4]*(NumPerTm-4.06154)	2.174915	0.265079	8.20	<.0001*
DistBetw Tw rs[2]*(Tw rSlew Rate-2.03077)	1.5164155	0.235583	6.44	<.0001*
DistBetw Tw rs[4]*(Tw rSlew Rate-2.03077)	-1.516416	0.235583	-6.44	<.0001*
MSTAR[No]*(CommReliability-50.0308)	-0.567596	0.278136	-2.04	0.0416*
MSTAR[Yes]*(CommReliability-50.0308)	0.5675963	0.278136	2.04	0.0416*
MSTAR[No]*(EntitySpeed-8.50769)	1.3529832	0.274757	4.92	<.0001*
MSTAR[Yes]*(EntitySpeed-8.50769)	-1.352983	0.274757	-4.92	<.0001*
MSTAR[No]*(NumPerTm-4.06154)	3.457763	0.26481	13.06	<.0001*
MSTAR[Yes]*(NumPerTm-4.06154)	-3.457763	0.26481	-13.06	<.0001*
MSTAR[No]*(Tw rSlew Rate-2.03077)	0.5327884	0.232862	2.29	0.0224*
MSTAR[Yes]*(Tw rSlew Rate-2.03077)	-0.532788	0.232862	-2.29	0.0224*
(Cam1ClassRng-150.031)*(Cam2ClassRng-190.031)	-2.359057	0.655455	-3.60	0.0003*
(Cam1ClassRng-150.031)*(EntitySpeed-8.50769)	-1.3098	0.574471	-2.28	0.0229*
(Cam1ClassRng-150.031)*(EntityStealth-0.50031)	0.8555647	0.509648	1.68	0.0936
(Cam1PClass-5003.08)*(CommReliability-50.0308)	-1.570068	0.631957	-2.48	0.0132*
(Cam1PClass-5003.08)*(Tw rSlew Rate-2.03077)	1.5608138	0.413492	3.77	0.0002*
(Cam2ClassRng-190.031)*(Cam2PClass-5003.08)	4.0188281	0.573359	7.01	<.0001*
(Cam2PClass-5003.08)*(CommLatency-64.0821)	1.5086946	0.440134	3.43	0.0006*
(CommLatency-64.0821)*(EntitySpeed-8.50769)	1.7999482	0.432194	4.16	<.0001*
(EntitySpeed-8.50769)*(EntityStealth-0.50031)	3.3704508	0.560603	6.01	<.0001*

Figure 15. Scaled estimates of the preferred stepwise regression used in the study. The *t*-ratio column explains the relationship between the factor and the MOE.

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
COCsWithMon{0&1-2}	1	1	1994.78	91.6096	<.0001*
COCsWithMon{0-1}	1	1	1447.26	66.4653	<.0001*
DistBetw Tw rs	1	1	283022.82	12997.75	0.0000*
MSTAR	1	1	4027.23	184.9494	<.0001*
Cam1ClassRng	1	1	475.51	21.8377	<.0001*
Cam1PClass	1	1	971.48	44.6151	<.0001*
Cam2ClassRng	1	1	135.83	6.2380	0.0127*
Cam2PClass	1	1	1243.72	57.1173	<.0001*
CommLatency	1	1	189.99	8.7252	0.0032*
CommReliability	1	1	0.56	0.0257	0.8728
EntitySpeed	1	1	8058.53	370.0861	<.0001*
EntityStealth	1	1	2540.17	116.6568	<.0001*
NumPerTm	1	1	11396.17	523.3660	<.0001*
Tw rSlew Rate	1	1	5607.36	257.5164	<.0001*
COCsWithMon{0&1-2}*DistBetw Tw rs	1	1	1721.92	79.0790	<.0001*
COCsWithMon{0-1}*DistBetw Tw rs	1	1	485.23	22.2840	<.0001*
COCsWithMon{0&1-2}*MSTAR	1	1	4439.63	203.8886	<.0001*
COCsWithMon{0-1}*MSTAR	1	1	1216.78	55.8801	<.0001*
COCsWithMon{0-1}*EntitySpeed	1	1	47.11	2.1637	0.1417
COCsWithMon{0&1-2}*NumPerTm	1	1	820.01	37.6587	<.0001*
COCsWithMon{0-1}*NumPerTm	1	1	596.26	27.3831	<.0001*
DistBetw Tw rs*MSTAR	1	1	3610.72	165.8216	<.0001*
DistBetw Tw rs*Cam1ClassRng	1	1	106.53	4.8922	0.0273*
DistBetw Tw rs*Cam1PClass	1	1	630.25	28.9440	<.0001*
DistBetw Tw rs*Cam2PClass	1	1	641.38	29.4554	<.0001*
DistBetw Tw rs*CommLatency	1	1	248.34	11.4048	0.0008*
DistBetw Tw rs*EntitySpeed	1	1	382.73	17.5768	<.0001*
DistBetw Tw rs*EntityStealth	1	1	699.26	32.1135	<.0001*
DistBetw Tw rs*NumPerTm	1	1	1465.84	67.3183	<.0001*
DistBetw Tw rs*Tw rSlew Rate	1	1	902.20	41.4331	<.0001*
MSTAR*CommReliability	1	1	90.68	4.1645	0.0416*
MSTAR*EntitySpeed	1	1	528.01	24.2487	<.0001*
MSTAR*NumPerTm	1	1	3712.57	170.4988	<.0001*
MSTAR*Tw rSlew Rate	1	1	113.99	5.2349	0.0224*
Cam1ClassRng*Cam2ClassRng	1	1	282.06	12.9536	0.0003*
Cam1ClassRng*EntitySpeed	1	1	113.20	5.1985	0.0229*
Cam1ClassRng*EntityStealth	1	1	61.36	2.8182	0.0936
Cam1PClass*CommReliability	1	1	134.41	6.1725	0.0132*
Cam1PClass*Tw rSlew Rate	1	1	310.26	14.2485	0.0002*
Cam2ClassRng*Cam2PClass	1	1	1069.79	49.1299	<.0001*
Cam2PClass*CommLatency	1	1	255.85	11.7499	0.0006*
CommLatency*EntitySpeed	1	1	377.67	17.3446	<.0001*

Figure 16. Sum of squares of the preferred stepwise regression used in the study. The sum of squares column explains the proportion of variance explained by each factor in the stepwise regression model.

Figure 17 shows an interaction plot of factors included in the preferred regression model. An interaction indicates that the change in the MOE caused by varying one parameter is dependent upon the value of another parameter. In an interaction plot, the MOE is on the y-axis and the factors involved in the interaction are on the x-axis or appear as separate lines as indicated in the legend. The trellis plot containing the interactions shows the high and low levels of the factor on the row and the trend in the MOE by changing the factor in the column. For example, Figure 17 (box all the way to the right in the second row) shows the interaction between *Role-player Stealth* and *Tower Slew Rate*. This graphic indicates: When *Role-player Stealth* is very high, the Tower Slew Rate has only marginal effect on the MOE; however, when *Stealth* is low, increasing the *Tower Slew Rate* improves the *Mean-Percent-Correctly-Identified*.

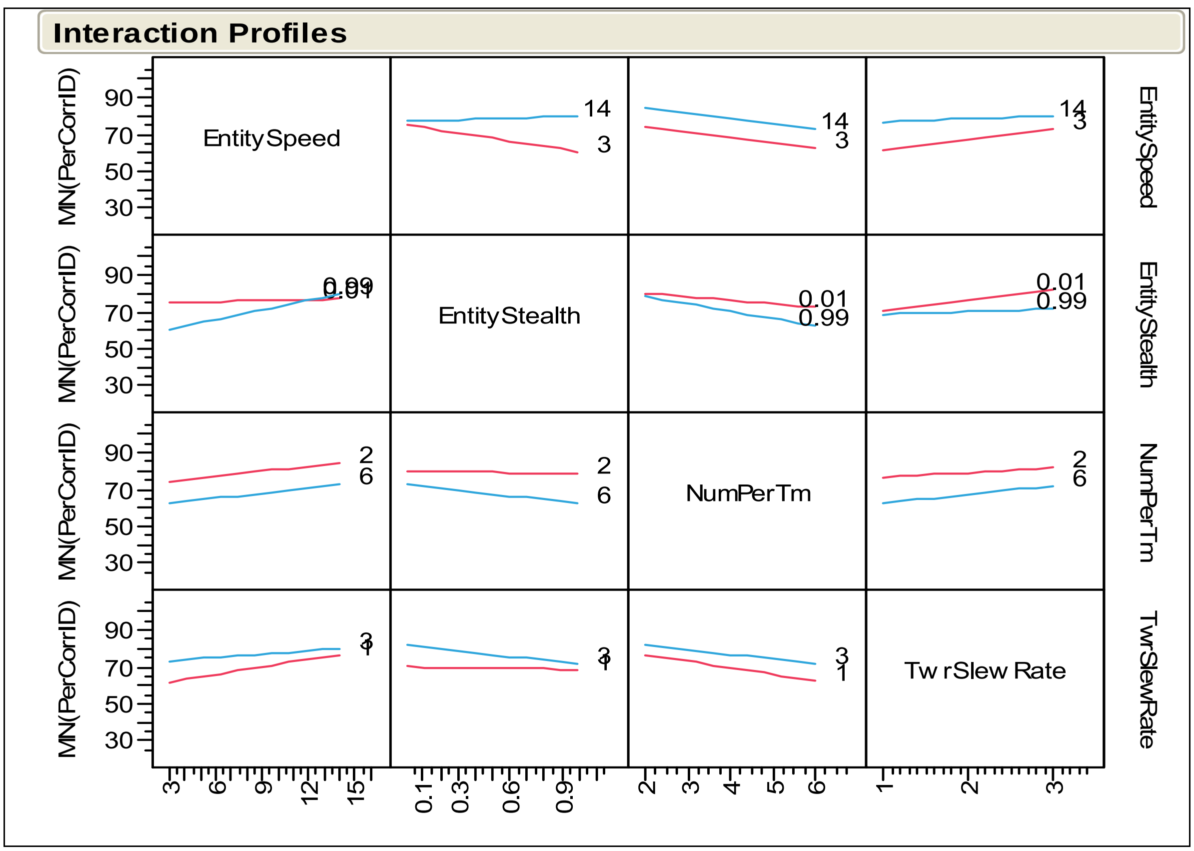


Figure 17. Interaction plots of four critical factors that determine the level of SA.

Figure 18 is a contour plot that reinforces the effect of the interaction between *Tower Slew Rate* and *Role-player Stealth* has on the MOE. In this plot, the slower G-BOSS slews its field-of-regard, the less stealth is required to avoid detection. The stealth level used by snipers and IED emplacers affects the MOE regardless of the G-BOSS slew rate.

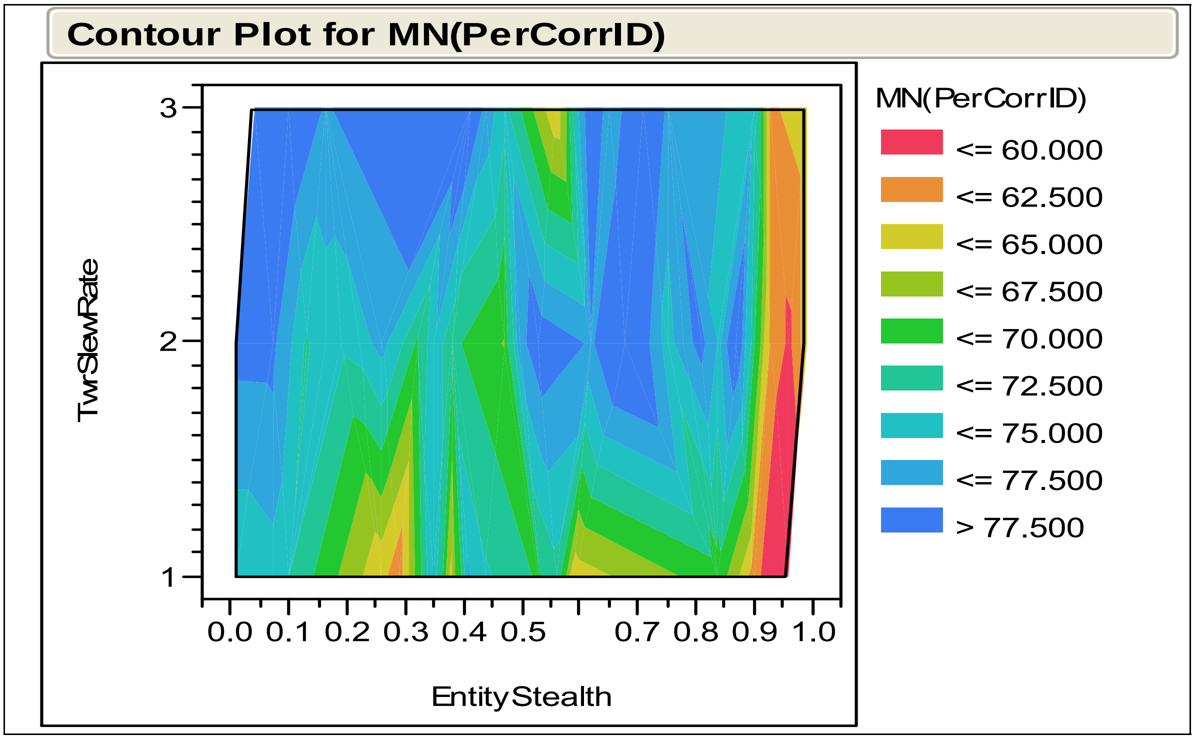


Figure 18. Contour plot of interaction between *Tower Slew Rate* and *Role-player Stealth*, and their effect on the MOE.

2. Regression Trees

Regression trees are another effective tool used to analyze the relationship between factors and MOEs. A regression tree is a recursive partition of the raw data into sets of inputs containing similar responses. Partitioning of the data occurs successively, according to the optimal splitting value determined from all possible values of each available variable. Figure 19 displays a recursive split of the data from 780 MANA runs on all of the experimental factors for the *Mean-Percent-Correct-Identifications* MOE.

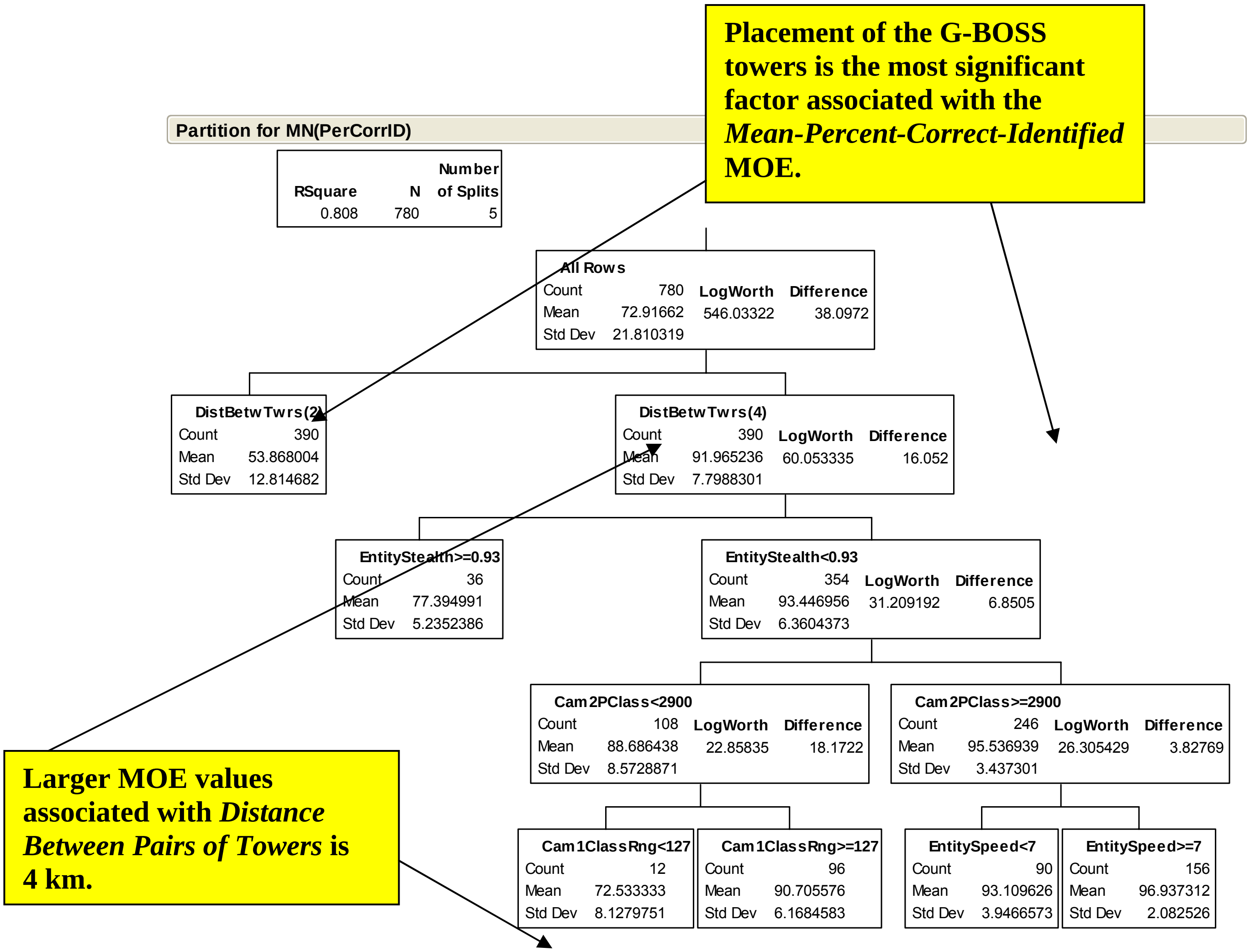


Figure 19. Regression tree split on the raw data by *Mean-Percent-Correct-Identifications* of Correct Identifications.

This analysis complements the regression analysis in the previous section. The first split is made on *Distance Between Pairs of Towers*. This is the single most significant factor identified. The regression tree provides the optimal split point at 2 km and 4 km. G-BOSS towers placed 4 km apart provide a mean percent of correctly identified role-players nearly two times greater than G-BOSS towers placed 2 km apart.

The next most important factor is *Role-player Stealth*. When G-BOSS towers are placed 4 km apart and a sniper or IED emplacer's stealth is less than 0.93, the expected percent of correct identifications is 93%. If *Role-player Stealth* is greater than or equal to 0.93, then the percent of correct identifications drops to 77%. Although the particular value of 0.93 does not translate directly to the real world, one of the key "uncontrollable

factors" is highly significant. This is a notable result. Perhaps countermeasures to enemy stealth can offset this effect. For example, training G-BOSS operators to a higher level of vigilance and detailed classification of "suspicious" behavior may be suitable countermeasures. Other significant factors identified by the regression tree include:

- *Camera 2 P(Classification)*
  - (best when greater than .29)
- *Camera 1 Classification Range*
  - (best when greater than 127 model grid squares, which is roughly equivalent to 2.5 km)
- *Role-player Speed*
  - (best when they are moving at speeds greater than 7/100 grid squares per time step, which is roughly equivalent to 1 km/hr)

C. COC COORDINATION VERSUS STAND-ALONE COMPARISONS

This section examines whether the simulation results of a coordinated configuration of G-BOSS improved operational effectiveness. This analysis is based on both MOEs. The following comparisons are conducted:

- Coordinated configuration of G-BOSS against stand-alone configuration without MSTAR (distance between towers is set at 2 km).
- Coordinated configuration of G-BOSS against stand-alone configuration with MSTAR (distance between towers is set at 2 km).

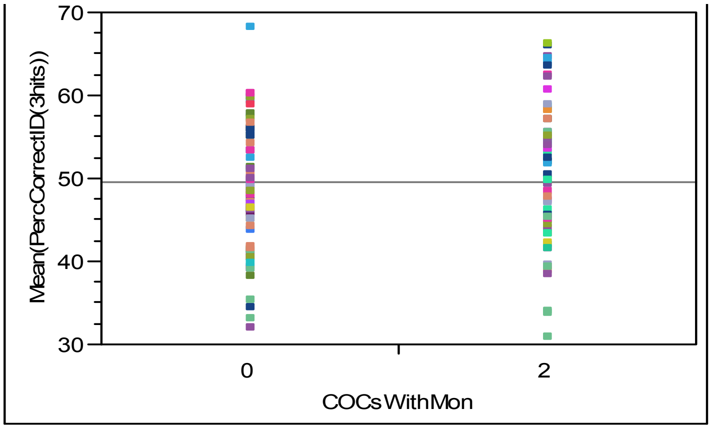
The MOE data does not fit a Normal distribution. Thus, a nonparametric statistical technique is used. The Wilcoxon Signed Ranks Test is designed to test whether a particular sample came from a population with a specified mean or median (Conover, 1999).

1. Coordinated versus Stand-Alone Configurations without MSTAR

This analysis is conducted as a hypothesis test. The null hypothesis is that the differences between two independent populations of simulation data from a coordinated G-BOSS configuration and a stand-alone configuration have the same mean. The alternative hypothesis is that the means are not equal. The notation used for this test is:

$$Mean(PercentCorrectID)_{Coordinated\_Configuration\_without\_MSTAR} \sim F$$
$$Mean(PercentCorrectID)_{S\tan d\_Alone\_Configuration\_without\_MSTAR} \sim G$$
$$D = F - G$$
$$H_0 : E(D) = 0$$
$$H_1 : E(D) \neq 0$$

Figures 20 and 21 show that without the presence of MSTAR, the means between the coordinated G-BOSS approach and the stand-alone G-BOSS configuration are not equal. There is evidence to reject the null hypothesis at a 0.05 or 0.10 level of significance. This conclusion is based on the p-value (0.0001). There is a statistically significant increase in performance between the networked configuration and the stand-alone configuration. This finding is due to an increase of approximately two percentage points between the two configurations. The small difference between the two configurations is so small that it should not be considered a practical significant difference. In other words, there is not enough evidence to deem the coordinated configuration more effective than the stand-alone configuration, based on the marginal increase in performance.



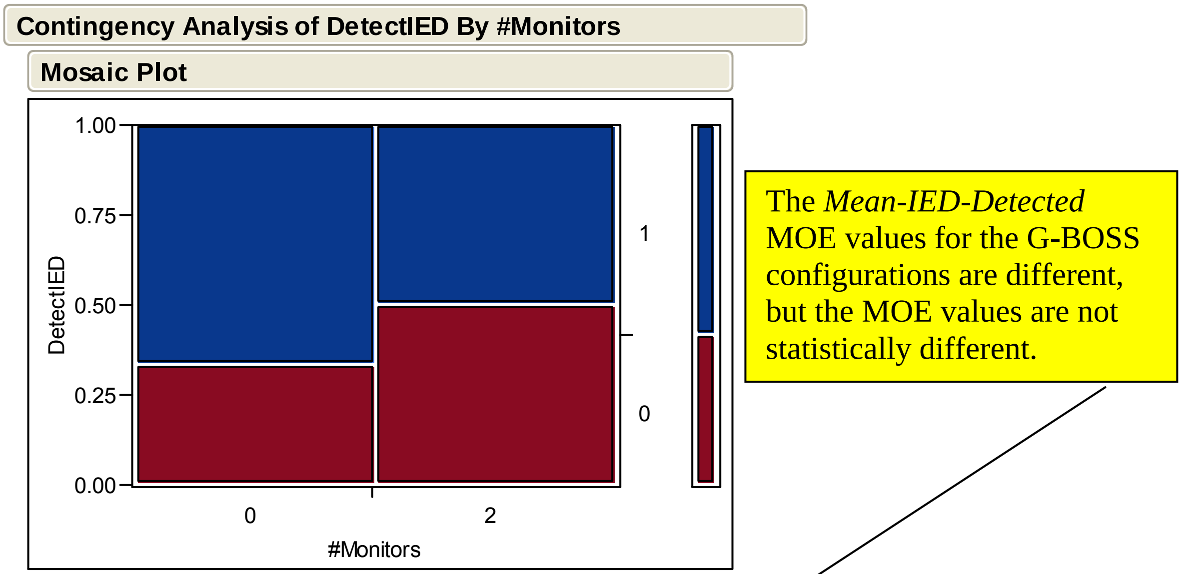
2Mon-Mean(PercCorrectID)	50.6272	t-Ratio	5.17721
0Mon-MeanPercCorrectID)	48.6322	DF	64
Mean Difference	1.99504	Prob > |t|	<.0001*
Std Error	0.38535	Prob > t	<.0001*
Upper95%	2.76487	Prob < t	1.0000
Low er95%	1.22521		

Wilcoxon Sign-Rank

	2Mon-Mean(PercCorrectID)-0Mon-MeanPercCorrectID)
Test Statistic	705.500
Prob > |z|	<.0001*
Prob > z	<.0001*
Prob < z	1.0000

The *Mean-Percent-Correct-Identification* MOE values for the two G-BOSS configurations differ by a very small margin. There is no practical statistical

Figure 20. Wilcoxon SignedRank Test results for coordinated G-BOSS configuration against stand-alone G-BOSS configuration for the *Mean-Percent-Correct-Identification* MOE. (No MSTAR)



Tests

N	DF	-LogLike	RSquare (U)
60	1	0.86175549	0.0211

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	1.724	0.1892
Pearson	1.714	0.1904

Figure 21. Wilcoxon Signed Rank Test results for coordinated G-BOSS configuration against stand-alone G-BOSS configuration for the *Mean-IED-Detected* MOE. (No MSTAR)

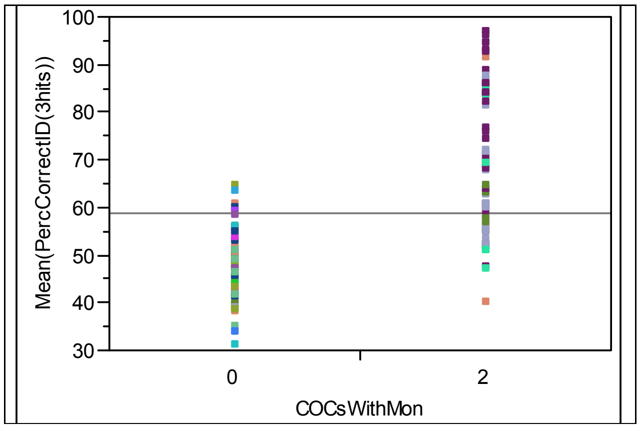
2. Coordinated versus Stand-alone Configurations with MSTAR

This analysis is conducted as a hypothesis test in a similar manner:

$$Mean(PercentCorrectID)_{Coordinated\_Configuration\_with\_MSTAR} \sim F$$
$$Mean(PercentCorrectID)_{S\tan d\_Alone\_Configuration\_with\_MSTAR} \sim G$$
$$D = F - G$$
$$H_0 : E(D) = 0$$
$$H_1 : E(D) \neq 0$$

Figures 22 and 23 show that with the presence of MSTAR, the means between the coordinated G-BOSS approach and the stand-alone G-BOSS configuration are not equal. Thus, there is enough evidence to reject the null hypothesis at a 0.05 or 0.10 level of significance. This conclusion is based on the low p-value (0.0001). There is both a

statistically and practically significant increase in performance with the networked configuration as compared to the stand-alone configuration. The performance with the networked configuration increases by nearly 25% (from approximately 47% correct classifications to about 70% correct classifications). This increase is significant enough to deem the coordinated configuration more effective than the stand-alone configuration based on the marginal increase in performance.



2Mon-Mean(PercCorrectID)	69.8949	t-Ratio	12.73921
0Mon-Mean(PercCorrectID)	47.4422	DF	64
Mean Difference	22.4527	Prob > |t|	<.0001*
Std Error	1.76249	Prob > t	<.0001*
Upper95%	25.9737	Prob < t	1.0000
Low er95%	18.9318		
N	65		
Correlation	0.4191		

Wilcoxon Sign-Rank

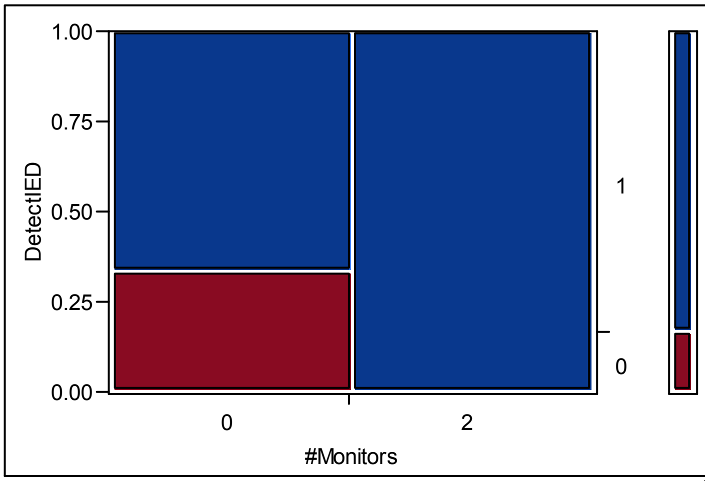
	2Mon-Mean(PercCorrectID)-0Mon-Mean(PercCorrectID)
Test Statistic	1069.50
Prob > |z|	<.0001*
Prob > z	<.0001*
Prob < z	1.0000

The *Mean-Percent-Correct-Identification* MOE values for the two G-BOSS configurations differ by a large margin. The differences in the MOE values are statistically different.

Figure 22. Wilcoxon Signed Rank Test results for coordinated G-BOSS configuration against stand-alone G-BOSS configuration (with MSTAR).

Contingency Analysis of DetectIED By #Monitors

Mosaic Plot



The *Mean-IED-Detected* MOE values for the G-BOSS configurations are very different. The MOE values are statistically different.

Tests

N	DF	-LogLike	RSquare (U)
60	1	7.9382475	0.2936

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	15.876	<.0001*
Pearson	12.000	0.0005*

Figure 23. Wilcoxon Signed Rank Test results for coordinated G-BOSS configuration against stand-alone G-BOSS configuration for the *Mean-IED-Detected* MOE. (With MSTAR)

V. CONCLUSIONS

This research set out to determine how Marines deployed *now* can best employ G-BOSS. An operational test of G-BOSS conducted by MCOTEA is the basis for the simulation model created in this study. This thesis produced a comparative, quantitative analysis of G-BOSS employment TTPs and the critical factors that determine the level of SA provided by G-BOSS. The results of this thesis provide insights to enhance operational effectiveness of G-BOSS. Furthermore, the simulation built for this research can serve as the foundation for many additional studies.

A. ANALYSIS INSIGHTS

The insights gained in this analysis are:

- The positioning of the towers is the most critical factor associated with enhancing the operational effectiveness of G-BOSS. A distance of 4 km between G-BOSS towers results in a proportion of correct identifications of 0.91 while a distance of 2 km results in a proportion of 0.53. When G-BOSS is employed in open terrain, more dispersion results in better performance.
- The stealth of the role-players has a significant effect on the proportion of correct identifications. This result is intuitive and helps validate the model, since snipers and IED emplacers tend to use stealth to mask their hostile acts or intent. Increased training of G-BOSS operators' level of vigilance is a countermeasure to mitigate enemy stealth.
- The interaction between tower slew rate and stealth of the role-players is significant. A faster G-BOSS slew rate provides a greater proportion of correct identifications when role-players' stealth is low. When role-players' stealth is high, a low proportion of correct identifications is achieved, regardless of tower slew rate. Recall that tower slew rate is the model's surrogate for the speed at which G-BOSS operators can observe a field-of-regard.
- Without the presence of MSTAR, the coordinated G-BOSS configuration produces a slightly larger proportion of correct identifications than the stand-alone G-BOSS configuration. The coordinated G-BOSS configuration results in an overall proportion of correct identification of 0.51, while the stand-alone G-BOSS configuration results in an overall proportion of correct identification of 0.49. The results of the comparison between the G-BOSS configurations are not practically significant. This

is based on the marginal increase of approximately two percentage points between the coordinated G-BOSS configuration and the stand-alone G-BOSS configuration. Further, this finding answers the question of underutilization: Stand-alone employment of G-BOSS is nearly as effective as a coordinated employment of G-BOSS without MSTAR.

- With MSTAR, the coordinated G-BOSS configuration produces a significantly larger proportion of correct identifications than what the stand-alone configuration produces. The coordinated G-BOSS configuration results in an overall proportion of correct identifications of 0.71 and the stand-alone configuration results in an overall proportion of correct identifications of 0.47. This result is practically and statistically significant. MSTAR facilitates the detection of more agents. MSTAR coupled with data fusion at the COC affords commanders an enhanced capability.
- The emplacement of the IED was detected in 76% of all of the simulation excursions conducted (which varied 13 factors associated with GBOSS or the role-players). This is promising since G-BOSS's mission is to counter the threat of IEDs.

B. FOLLOW-ON WORK

The following is a list of follow on research of value stemming from this research:

- Additional validation and comparison of the MANA simulation results with the results of MCOTEA's live experiment.
- Further research into the utility of using simulation to develop synthetic operational experiences in new doctrine and tactics.
- Human factors study on how the vigilance of G-BOSS operators affects the level of SA provided by G-BOSS.
- Application of the findings in this thesis on enhancing the operational effectiveness of G-BOSS in an urban environment.
- Research into the operational effectiveness provided by G-BOSS when integrated with various organic assets (UAS, C2 assets, and Fire Support Systems).

LIST OF REFERENCES

Cioppa, T.M., & Lucas, T.W. (2007). “Efficient Nearly Orthogonal and Space-Filling Latin Hypercubes.” *Technometrics*, 49 (1), p. 45.

Conover, W.J. (1999). *Practical Nonparametric Statistics*. 3rd Edition. New York, NY: John Wiley & Sons, pp. 352-356.

Defense Acquisition University 10th edition Glossary. Available at https://acc.dau.mil/simplify/ev.php?ID=23461_201&ID2=DO_PRINTPAGE.

Endsley, M.R., & Garland, D.J. (2000). *Situation Awareness Analysis and Measurement.* Mawah, NJ: Lawrence Erlbaum Associates, p. 5.

Marine Corps Combat Development Command. (2007). “G-BOSS Operational Concept, Coordinating Draft.” Combat Development Directorate, Force Protection Integration Division, p. 2.

McIntosh, G.C., Galligan, D.P., Anderson, M.A., & Lauren, M.K. (2007). “MANA Help File.” *MANA (Map Aware Non-Uniform Automata) Version 4 User’s Manual,* Defence Technology Agency, New Zealand, pp. 1-6.

Montgomery, D.C., Peck, E.A., & Vining, G.G. (2006). *Introduction to Linear Regression Analysis*. 4th Edition. Hoboken, NJ: John Wiley & Sons Inc., pp. 63-75.

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. Joint Improvised Explosive Device Defeat Organization (JIEDDO)
   Crystal City, Virginia

4. Marine Corps Operational Test and Evaluation Activity (MCOTEA)
   Quantico, Virginia

5. Marine Corps Systems Command (MCSC)
   Quantico, Virginia

6. Marine Corps Combat Development Command (MCCDC)
   Quantico, Virginia